IDENTIFICATION AND DELINEATION OF URBAN RIPARIAN ZONES AND THEIR INFLUENCE ON LOCAL ENVIRONMENTAL CONDITIONS

Final Report

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INTRODUCTION

BACKGROUND

To best manage water resources the spatial and temporal dimensions of the resource must be characterized. By knowing where and when the various components of the hydrologic cycle interact, informed decisions can be made on how to manage a watershed (Nystrom, *el al.*, 1985). This project represents one step in a multi-stage process to develop the components necessary to model the urban watersheds of Baton Rouge. To attain this goal, it is imperative to represent the interaction between waterbodies (streams, lakes, bayous, *etc.*) and their surrounding landscapes. This requires spatial data that represents the drainage network and adjacent land use patterns.

As is typical of urban areas, Baton Rouge has a number of predictable and well-documented water quality problems (Louisiana Department of Environmental Quality. 1993a, 1993b, 2000). These are exacerbated by the continuing pressures to develop open land to meet demands of residential and commercial interests. Urban development alters the spatial characteristics of watersheds and causes the hydrologic cycle to become un-balanced. The balance between the various components of the hydrologic cycle maintains the dynamic equilibrium of stream structure and function. Any changes in the cycle produce water quality and quantity alterations, as well as alterations in the geomorphology of the waterbody (*i.e.*, channel incising, streambed filling, *etc.*).

To avoid adverse changes in environmental quality, informed planning and management principals must be applied. This requires data and models to evaluate management alternatives. Urban development is quickly changing the landscape of Baton Rouge. Many of these problems are already present. Flooding and "drainage" issues are the most apparent. To address these, the US Army Corps of Engineers has proposed various management approaches that greatly alter the geomorphology of the drainage network of the Parish. These do not account for the contribution natural riparian habitats make in water quality mitigation (US Army Corps of Engineers, 1995). In 1999, the City-parish of East Baton Rouge determined that local sanitary and storm sewer problems required nearly $500,000,000 in repairs.

This project was conceived, initially, from the simple question, "How many miles of streams and waterbodies traverse East Baton Rouge Parish?" There was no readily available answer to that question. Despite its simple appearance, answering this question is quite complex. It cannot simply be taken off a map. This is because maps of different scales have different levels of resolution. Therefore, each map generates a different length for the same stream segment. Large scale, 1:24,000, (fine resolution) electronic (GIS) data are not readily available for the entire area of East Baton Rouge Parish. Only relatively coarse, 1:100,000 scale digital data are available for the whole Parish.

Another complication to answering this question is the definition of what comprises a waterbody. Categories of waterbodies depend on their functional and geographic definitions. Determining this is necessary to decide what geographic features are to be included in such an inventory. For example, it can be very difficult deciding where to start mapping a waterbody. Many streams, creeks, and bayous start as small ditches in an upland or urban area. As several drainage ditches combine, they give rise to a creek or bayou. In general, urban landscapes are a patchwork pattern of various land uses and land covers. Baton Rouge is no exception. Like most southern cities, it is located on upland, formerly forested sites and has been extensively altered by transportation, drainage "improvements," and land development. Much of the Parish is now "urban forest."

The overall spatial pattern of the Baton Rouge urban forest has two primary dimensions. First, is land use. This is defined as how a parcel of land is managed and used by man. It includes such activities as agriculture, commercial, residential, developed or undeveloped, *etc.* The second dimension is land cover. This is defined as the nature of the vegetative cover on an area. It can be defined in various ways. For example, percent vegetative cover, ecological community, or some other classification scheme. These combine to create new land use/land cover classes from their interaction. Urban forest, for example, is an urban land use (say, residential or commercial) with a forest canopy cover type (*i.e.*, greater than 50 percent tree cover or mainly closed canopy).

Remote sensing can be a useful tool for this application, because it captures the spectral and radiometric responses created by the interactions between land use and land cover (Chang, 1981; Ellis and Woitowich, 1989; Rivereau and Pousse, 1990). The first phase of this project investigates the use of remotely sensed data from two different sensors that are merged into a single presentation. This process is done to provide improved resolution and information content of the study area. The data sources are Landsat Thematic Mapper (TM) data and SPOT Panchromatic data. Both are readily available commercial products. The Louisiana Department of Environmental Quality (DEQ) uses these data in a number of projects and is already familiar with their use and production. The statewide coverage makes this an ideal prospect for developing techniques that can be applied across the state. Furthermore, the cost of this spatial data source makes it more economical than extensive aerial photography.

The second phase of this project utilizes aerial photography to analyze hydrographic features and classify them. Once identified, these features are mapped to existing vector-format (GIS) data. Using this approach, a map of riparian habitat and near-stream land use is created.

Phase three uses macroinvertebrate-based water quality indices to determine how the mapped watershed characteristics relate to the observed water quality. Using a single watershed, a longitudinal study will examine how changing land use patterns and riparian habitat, along the length of the watershed are related to water quality.

OBJECTIVES

In this project, conventional aerial photographic interpretation was compared with an automated method to map riparian habitats. With these tools, the original question of how many miles of waterbodies exist in the Parish could be determined (Chidley and Drayton, 1986), with reasonable reliability. Furthermore, DEQ, local planners, and environmental regulators can evaluate the effect of various activities and development scenarios on water quality and runoff volume. With the data in a GIS format, changes can be updated relatively quickly and efficiently and their impacts assessed (Chang, 1981).

An important facet of this project is to determine whether the merged SPOT-TM image is more useful than conventional aerial photography for environmental interpretation directed at management applications. At the time the project was proposed, there was little use of this form of spatial data, other than as an aesthetic backdrop to digital vector (line) data. There was no use of these data in the water management programs of DEQ. If riparian habitat could be successfully mapped, the methodology could be reproduced across the state.

The final products of this project are the development of a geospatial database of local waterbodies that describes:

1. Riparian habitat, on each bank.

2. Local land use, on each side, near the waterbody.

Finally, these data provide a basis for designing a macroinvertebrate sampling survey to determine waterbody health (Richter, *et al.*, 1997; Louisiana Department of Environmental Quality. 2001; Palmer, *et al.*, 2000). The analysis of macroinvertebrate diversity combined with the mixture of land use and riparian habitat provides a foundation for determining the influence of development on water quality in urban areas.

METHODS

DATA AND MATERIALS

The basis for the evaluation in this project are areal photographs provided by the East Baton Rouge Parish Office of Landscape and Urban Forestry and the SPOT-TM image produced by the GIS Lab of the Louisiana Department of Environmental Quality (Braud, 1997). The most important features of the image data are:

1. Spatial resolution of 10 meters

   To produce a useful GIS product, it must serve the needs of the users. In this case, linear water features were to be identified. The 10 meter (~33 feet) resolution was thought to be sufficient for tracing most of the important riparian features in East Baton Rouge Parish. For practical reasons, a minimal mapping unit of 10^2 meter^2 is appropriate for capturing the intrinsic scale (natural variability) of the underlying spatial processes (Chidley and Drayton, 1986).

2. Spectral characteristics that allow for identification of natural and urban features.

   The complex spatial interactions between natural and man-made features that pervade the urban landscape are important to characterize. The TM part of the data are useful in characterizing the natural features (Garrett, et al., 1977). Spectral bands 4, 5, and 3 were chosen because of their sensitivity to natural features. Band 4 operates in the near infra-red spectral region and is primarily used for distinguishing vegetation varieties and water bodies. Band 5 operates in the mid-infra-red region and is responsive to variations in water content for both leaf-tissue and soils. Band 3 operates in the visible red portion of the spectral region and is highly sensitive for discriminating differences in vegetation and soil (Avery and Berlin, 1992).

   The SPOT Panchromatic part of the data is an excellent product for identifying the shapes of urban features (Rivereau and Pousse, 1990). The spatial resolution of the TM data is approximately 30 meters, while the SPOT data are 10-meter resolution (Braud, 1997). Combining the two provides the best features of both in spatial resolution and spectral response.

3. The data are available to DEQ through the DEQ GIS lab.

   These data are complicated to produce and voluminous to store. Data management issues can be time consuming and extensive. With the product developed and maintained in the GIS Lab, users of the data are able to concentrate in its use and application to their purposes. Furthermore, GIS lab personnel can provide technical support to users; maintain data integrity, and data security.

4. The spatial data have statewide coverage.

This database was produced with the concept of providing data that covers the entire state. As a result, the data resolution and content is consistent and its use and application can be reproduced across the state. This is an important feature for data used in statewide organizations such as DEQ. Once techniques are developed in one locale, they can be applied across the state.

All geospatial data used in this project were obtained from the USGS (with the exception of DEQ's SPOT-TM image, the aerial photographs, and the CAD data obtained from the East Baton Rouge Parish, Department of Public Works, DPW). The aerial photos were provided in native format. DPW data were obtained on CD-ROM, in CAD drawing file (.DWG) format. The USGS data are routinely distributed through various WWW sites. The main point of access is:

http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html

Streamflow and water quality data were obtained from the USGS Water Resources Division, Regional Office, located in Baton Rouge, Louisiana. Maps and lists of partial record, peak flow stations and water quality stations appear is Appendices A. and B.

SOFTWARE

All data manipulation in this project was performed using the *SAS System*®. Digital geospatial data were manipulated using *ARC/INFO*® and *Arcview*® published by the Environmental Systems Research Institute. *Imagine*® from ERDAS was used to perform image analysis.

APPROACHES

Riparian Habitat Classification Scheme

A classification scheme was created to account for the major types of riparian habitats found in the Baton Rouge area. These are listed in Table 1.

These categories were determined, by field observation, to encompass the variety of the different types of waterbodies identified on the aerial photographs of Baton Rouge. They were chosen to describe hydrologically and ecologically significant habitats. Each type can be associated with different biological communities and environmental (water quality) functions. The interaction of substrates and channel morphology with biological communities will elicit different water quality responses. In addition, classes need to be created that can be identified in the image and photos. For example, sand and rock have a distinctive signature on the image. It appears as a very bright, light colored area and is quite distinct. Likewise forested riparian corridors are dark-green and very distinct.

Unfortunately, the image analysis could not distinguish between sand and gravel and concrete. These features have vastly different hydrologic functions.

**Table 1.
Classification Scheme for Riparian Habitats**

Category	Description
Tunnel	Underground passage, usually concrete
Concrete	Concrete lined channel
Low vegetation	Channel lined with mainly grass, small plants, or shrubs
Tree lined	Trees along bank with open canopy
Closed canopy	Trees along bank with closed canopy
Lake	Shoreline of areal waterbody

Land Use Classification Scheme

A classification scheme was created to inventory the major types of near-stream land uses found in the study area. These are listed in Table 2.

These categories were determined, by field observation, to encompass land use categories identified on the aerial photographs of Baton Rouge. This was done to provide data to examine the interaction of near-stream land use and riparian habitat with respect to water quality.

Radiometric and spectral similarity create problems in classifying the satellite image. Roads, sand, and rocks all appear very similar on the image. Visual inspection can differentiate these features through local context. They must be distinguished through prior knowledge or field observation. To overcome this problem and make image classification more efficient, this project proposed to use established, ancillary GIS data to differentiate between such features.

Ancillary Data

Several sources were identified for ancillary GIS data. Initially, standard sources such as the US Geological Survey (USGS) were investigated. As discussed previously, data of divergent scales will provide different characterizations of geographic features. This is particularly true for linear features. This difference is termed, "generalization." Generalization is the process of representing features in an appropriate manner as the scale decreases (becomes more
coarse). The simplest example of this is how the Mississippi River is represented on different maps. A world map of rivers (drawn at a scale of 1:5,000,000) shows the Mississippi River as

Table 2.
Classification Scheme For Near-stream Land Use

Category	Description
Agriculture	Agricultural - crops, pasture, or otherwise cultivated
Commercial	Urbanized - Shopping centers, parking lots, and industrial
Residential	Subdivision - -primarily open
Open	Open space – not agricultural, few or no trees
Forest	Primarily trees – closed or nearly closed canopy
Road	Road right of way – open, paved or unpaved
School	School yard, usually open, with some buildings and trees
Sand and Gravel	Open primarily unvegetated – previous or active mining
Lake	Shoreline of areal waterbody

it flows between Louisiana and Mississippi as a single line, with broad sweeping curves. On a USGS 7.5 Minute Series map (scale: 1:24,000), that same length of river would be represented with a left bank, right bank and with many twisting turns. The world map is said to be "generalized." The distance along the same segment of the river is represented by different lengths at each scale.

Generally, the best available GIS data are from the 1:24,000 scale, 7.5 Minute Map Series. However, there is not complete coverage of the East Baton Rouge Parish area in the digital format. The USGS 1:100,000 scale maps have complete coverage of Louisiana. This is what was initially used for ancillary data. During the project, it was discovered that the East Baton Rouge Parish Department of Public Works had digitized a number of maps for their purposes. Of particular interest, was their map identifying all canals, waterways, tunnels, and other features important to this project A great deal of effort was put into processing these data for use in this project. Much of this is described in quarterly reports. In summary, the data were produced in a CAD (computer aided design) environment and was converted to an ESRI GIS format for use in the project. That was relatively straightforward. However, the data were ultimately determined to be unusable as there was no information on its projection or source of data used in digitizing the maps. Without this information it was impossible to determine source scale, accuracy, or other important quality control factors. As a result, it was not possible to manipulate the data into a usable form.

Image Analysis

Initially, an unsupervised classification was performed on the image to identify "natural" classes of spectral response. If there are any clear spectral responses that delineate riparian habitats, they will be identified at this stage. More likely, the combinations of land cover and land use will interact to create a set of classes that define any particular type of habitat. For this reason, it was decided to limit analysis to areas, which were specifically identified by the GIS data, *a priori*, as lying along the linear hydrography features. Scale problems with the 1:100,000 scale GIS data made this impractical. This will be explained in the Results section. For this reason, analyses proceeded using the whole image and identifying patterns at that level.

The study area was defined by a box surrounding the boundary of East Baton Rouge Parish. The box allowed sufficient space to minimize any "edge effect" near the borders of the study area. Edge effect occurs along the periphery of any study area (Mitchell, 1995). It results from the lack of information available to various analytical algorithms. The algorithms employ a window that, along the edges, falls outside the image. Edge effect will always be present. By defining an extent that is sufficiently beyond the area of interest, the effect will not appear in the study area.

Without the ability to limit the image analysis to a subset of pixels located in close proximity to waterbodies, the entire image had to be analyzed. This does not change the general process of analyzing the image. However, it does increase the possibility of misclassifying features that are clearly not related to hydrography. It is important to recognize that image analysis is somewhat of an art. Classification is a two-step process. Identification is the first step. It involves the isolation of a distinct object. The second step, classification, is the characterization of identified objects.

The initial unsupervised classification is a purely numerical/statistical procedure that examines the spectral brightness (radiometric response) of the different sensor bands from the satellite (spectral response). This is done to define "natural' groups of spectral responses (signatures). Response is measured as a combination of reflectance values (radiometric response) for the combination of available spectral bands (spectral response). These categories or groups of objects have statistically similar responses.

The second step in the classification process is to categorize as many of these natural classes as possible. Each class is located on the image and ground truth used to determine the composition of the class. First stage, "natural" classes may be combined with other, similar classes. Many groups are very nonspecific, within the context of the classification objectives, and are assigned to the category, "unclassified." Often a large proportion of an image falls into this category (Wickware and Howarth, 1981).

Step three is the combination of like classes. How, and if, this is done depends on the objectives of the project, the uniqueness of what the classes identify, and the detail required. The same type of object, in different locations, may have different radiometric responses, depending on various conditions, in close proximity to each location. Urban environments, with a great deal of spatial variability, exhibit this phenomenon. For example, residential areas display strong signatures from streets and rooftops. As residential areas intermingle with various cover types, as in an urban forest, roofs and streets have different radiometric responses. As is discussed later, these interactions make urban forest analysis difficult. Temporal differences in images exacerbate this problem.

Aerial Photographic Interpretation and Map Production

Aerial photographs were visually interpreted by inspection and mapped onto vector data. The vector data selected for this were the USGS 1:100,000 scale hydrography from their Digital Line Graph (DLG) product (USGS, 2001). These data were chosen for their complete coverage of East Baton Rouge Parish. Because of modifications made to the natural stream network, the original DLG data were augmented by addition of arcs from the 1:24,000 scale DLG product. Some arcs also had to be digitized. Missing arcs [errors in the 1:100,000 product] were either transferred from the 1:24,000 product or digitized against the image as a background.

The land use categories identified in this phase of the project are listed in Table 2. These were selected as representative of the most hydrologically important and most easily discernable from the imagery and aerial photography.

Water Quality Assessment Using Macroinvertebrate Diversity

Under natural, *in situ*, conditions, water quality tests using traditional chemical methods only capture the conditions of that moment in time when the test is taken. This approach does not account for the changing water quality in the local environment, over time. Water moving downstream constantly changes the local environment, carrying pollutants and altering, temporarily, water quality. A sample on one day might indicate completely clean water, while a sample in the same place, the day before, or the day after, might test positively for any number of pollutants.

Macroinvertebrates, such as aquatic worms, leeches, clams, crawfish, snails, insect larvae, *etc.* are excellent indicators of water quality, because they live much of their life cycle in the same region of a stream. Each species has a different level of sensitivity to water pollution. Some species thrive in polluted water, while others cannot survive. In a healthy stream, the stream-bottom community will include a variety of pollution-sensitive macroinvertebrates. Unhealthy streams may have only a few types of nonsensitive macroinvertebrates (Palmer, *et al.*, 2000).

As a result, a survey of the macroinvertebrates in a stream represents a time-averaged measure of water quality. If a stream reach is consistently subjected to poor water quality, the macroinvertebrate community will reflect this. Likewise, streams that experience either a low frequency of environmental insults or low levels of pollutants will reflect better water quality indices.

To document the sampling, a "Louisiana Macroinvertebrate Stream Survey" form was provided by the Louisiana Department of Environmental Quality. The form requires information about each site including location, basic weather conditions, average stream width, average stream depth, current, habitat sampled, substrate composition, surface water appearance, stream bank vegetation, fish indicators, and other salient comments. The next step is to take a sediment sample with a dip net or seine. The macroinvertebrates are then collected and identified. Identification, for this study, was made to the family or genus. Each category is then counted.

Each indicator group is assigned a category based on the number of individuals present in the sample. Categories are assigned, using a logarithmic progression, as follows:

A = 1 – 9 individuals
B = 10 – 99 individuals
C = 100 – 999 individuals
etc.

The species are categorized into three water quality groups representing sensitive species, somewhat sensitive species, and tolerant species. The number of species (letters) in each water quality group is summed then multiplied by a group factor. These factors are:

1 = Tolerant
2 = Somewhat Tolerant
3 = Sensitive

These weighted values are added across all water quality categories to create a total index value. These values represent a measure of water quality that can be ranked along a continuum (Louisiana Department of Environmental Quality, 2001):

< 11 = Poor water quality
11 – 16 = Fair
17 – 22 = Good
> 22 = Excellent water quality

RESULTS

ANCILLARY DATA ANALYSIS

An important goal of this project was to determine whether an efficient and accurate method could be developed to identify riparian habitats from the SPOT-TM image. The complex radiometric and spectral response of land cover and land use made it important to determine whether riparian features show a unique signature within the image. Because this was not the case, it was first decided to use ancillary GIS data to predefine the riparian zones (Chidley and Drayton, 1986). By using these data to limit the area of analysis, a template was created to just examine riparian zones. For this, digital map (vector) data from the USGS were identified and evaluated.

The USGS 1:100,000 scale map series provided the only source of digital data that included the entire study area. The most appropriate source would have been the USGS 7.5 Minute map series, at a scale of 1:24,000. Unfortunately, there was not a complete set of 7.5 minute quadrangle maps available in digital format.

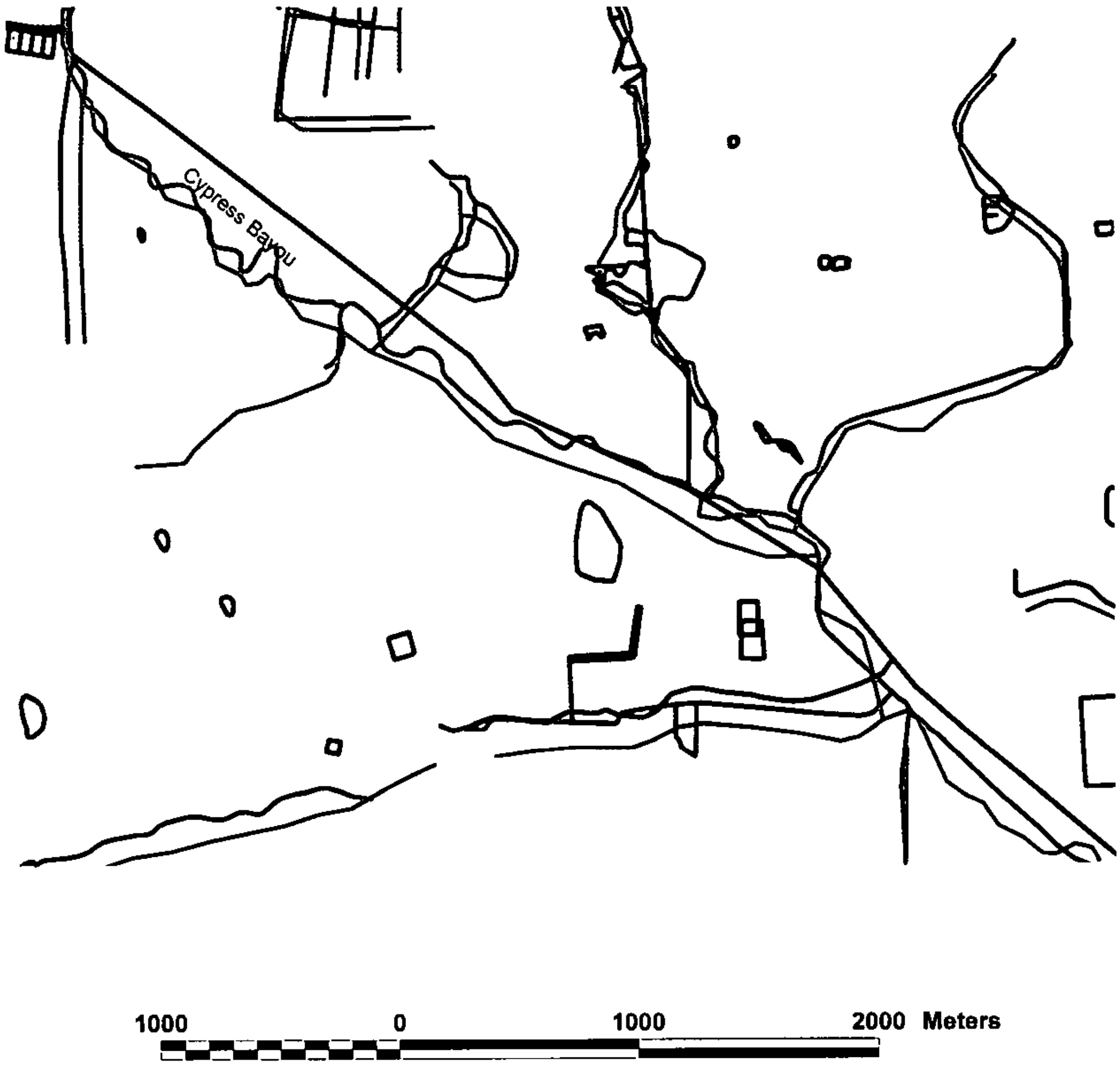
A careful examination of the 1:100,000 vector data revealed a poor level of coincidence between the image data and vector data. This is due to some combination of registration errors and scale differences. Scale determines the detail that can be represented by a given map. Table 3, shows the USGS national map standards data resolution for data used in this project.

Table 3.
The Relationship Between Scale and Resolution

Data Source	Map Scale	Minimum Resolution (meters)
DLG - vector	1:100,000	51
DLG - vector	1:24,000	12
TM - raster	1:58,937	30
SPOT - raster	1:19,641	10

Adapted from the US Geological Survey, National Mapping Division (1980). Scale for TM and SPOT were determined by extrapolating the data reported in the aforementioned source.

From Table 3, it is clear that the map scales and resolutions of the three data sources are quite different. This is demonstrated in Figures 1 and 2. For spatial analytical purposes, it is important to use the most accurate data available (Mitchell, 1995, 1996). For combining



1:24,000 scale - USGS 7.5 Minute Quadrangle
1:100,000 scale - USGS 30 X 60 Minute Quadrangle
Unknown scale - Baton Rouge DPW

Figure 1. Comparison of differences in vector data from different scales and sources.

1:24,000 scale - USGS 7.5 Minute Quadrangle
1:100,000 scale - USGS 30 X 60 Minute Quadrangle
Unknown scale - Baton Rouge DPW

Figure 2. Comparison of vector scale differences with SPOT-TM Image.

information between vector data sources and raster images, it is important to make sure that the vector data are, *at least*, as accurate as the raster. This was not the case in this project.

The second factor that impeded the use of vector data in this project was rectification and spatial registration. Rectification is the process of removing the distortion of the remote sensing device from the image. This results from the geometric relationships between the satellite positions, curvature of the earth, and angle of the sensor. This form of spatial error is always present and can be minimized through the process of rectification. This is probably not a major component in the lack of coincidence between vector and raster data.

Registration is probably the main factor in the problem of matching the vector data with the image. This presents a logical paradox. The source of the vector data is official USGS maps. They adhere to the standards for those map products (USGS, 1980). On the other hand, the image represents "reality." In fact, it is a picture of "the real thing." In that regard, how could it be wrong? This conflict creates a problem in consistency between products, as both represent the same location in space with different formats and both have their elements of accuracy and error. Nevertheless, the two do not coincide and cannot be combined with any accuracy.

During the execution of the project, it was discovered that the East Baton Rouge Parish Department of Public Works was digitizing its own data, including drainage patterns, hydromodification projects, and other hydrographic features. These were obtained from the Department and explored for their application to this project.

As was described in the Data and Material Section of this report, these data required extensive processing to register them to real-world coordinates. Once accomplished, the data were compared with the other vector data and the image. Unfortunately, this also led to a dead end with regard to use as a template for processing riparian zones (see Figures 1 and 2).

Due to the results described, above, the use of ancillary data to automate the classification of riparian habitats was abandoned. None of the data sources investigated coincided with each other. This is not completely surprising. Despite the fact that all the data represent the same location in space, they were all derived from different sources. This eliminates the possibility of automating riparian habitat identification from the SPOT-TM image.

ENVIRONMENTAL DATA ANALYSIS

In order to evaluate the relationship between riparian habitat characteristics and environmental responses, water quality and annual peak flow data were collected from the US Geological Survey, Water Resources Division, located in Baton Rouge, Louisiana. Exploratory data analysis was performed on these data. A listing of stations, their names, and maps of their locations appear in the appendices. Appendix A contains the water quality stations (Table A-1) and a list of water quality parameters sampled at those stations (Table A-2). Appendix B includes the peak flow/stage, partial record stations.

Because the delineation and characterization of riparian habitat were not successful, this phase of the project was abandoned. However, the data remain available and can be used in subsequent studies that examine the relationships between aerial (two-dimensional) watershed characteristics and environmental factors.

IMAGE DATA ANALYSIS

The manner in which the merged SPOT-TM image is produced creates a problem in interpretation for hydrologic modeling. The study area happens to fall in a location where four tiles of the statewide image meet. A tile is a panel that is independently processed and maintained in the overall database. In this database, each tile coincides with one map from the USGS 1:100,000 Map Series. Because they are independently produced, they are each rectified and registered to local ground-truth. This means that the nature of locational error is different in each panel. Clearly, the number of ground-truth locations that can be used for this process is limited on a statewide data product.

A further complication presented by the tiling scheme is the temporal sampling of data included in the area of interest. The statewide image is a composite of several sampling dates. It is impossible to get the entire state on a single pass of each satellite. Successive passes follow a different path. Each path is relatively parallel with the others, but occur hours or days later. On any given pass, cloud cover can be a problem. In addition, as the seasons pass, the sun angle changes. As the angle of the sun changes and the angle of the sensor relative to the earth changes, apparent spectral and radiometric responses change. To produce a visually consistent image, data representing several years of images were used. This image includes four samples from several different time periods (see Table 4).

The lack of coincidence in temporal sampling creates a problem with consistency in the image. This is a critical factor in the use of this type of data for hydrologic analysis. The role of evapotranspiration in the hydrologic cycle is so important that factors related to it must be correctly represented on the image. Canopy cover and leaf area index are of particular importance to evapotranspiration. The amount of greenness in the image is a measure of these factors. However, they are seasonal in nature. As the annual cycles of spring, summer, fall, and winter progress, the nature of the forest canopy and ground cover changes. This difference can also appear with inter-annual differences in weather and climate. Dry years and wet years will generate vegetation differences with concomitant differences in spectral and radiometric responses.

This problem is clearly shown in Figure 3. Here, various tiles of the image are distinctly different from the others. As can be seen in Table 4, some of the differences may be explained by the temporal differences of the source data combined in each tile.

Table 4. Sample Dates for the Four Panels of the Study Area

Upper Left			Upper Right		
	SPOT Dates:	01-08-95		SPOT Dates:	01-08-95
		01-19-95			01-24-95
	TM Date:	11-29-92		TM Date:	02-01-93
Lower Left			Lower Right		
	SPOT Dates:	01-08-95		SPOT Dates:	01-08-95
		01-19-95			01-24-95
	TM Date:	11-29-92		TM Date:	01-25-93

NOTE: All SPOT images include data sampled from two different dates (Braud, 1997).

The results of the image analysis are depicted in Table 5. As is clear from the listed categories, the features are mainly comprised of areal features. That is, objects that have two-dimensional shapes. Linear features are not well represented among these classes. The hydrologic features targeted for analysis in this project are only represented as Wetlands, Open Water (Figure 4), and "Hard Surfaces / Sand and Gravel /Rocks" (Figure 5).

The Open Water category is mostly comprised of Mississippi River, Amite River, and various lakes and ponds across the parish. Only the Comite River and Intracoastal Canal are apparent as linear hydrographic features on the classified image (see Figure 4). Wickware and Howarth, (1981) also experienced this. The image is also "peppered" with apparently randomly distributed features across the parish.

A striking feature of Figure 5 is its ability to identify highly urbanized areas. These are characterized by hard, impervious surfaces. It is interesting to note the pixel grouping in the downtown Baton Rouge area, Plaquemine, Bon Marche and Cortana Malls (the Mall of Louisiana was not yet constructed), and highways. Notably, the cities of Baker and Zachary do not display large areas of this classification. This implies that they have much less impervious area or open sand and gravel landscapes. The sand and gravel operations along the Amite River in the Northeast corner of the Parish are also well represented.

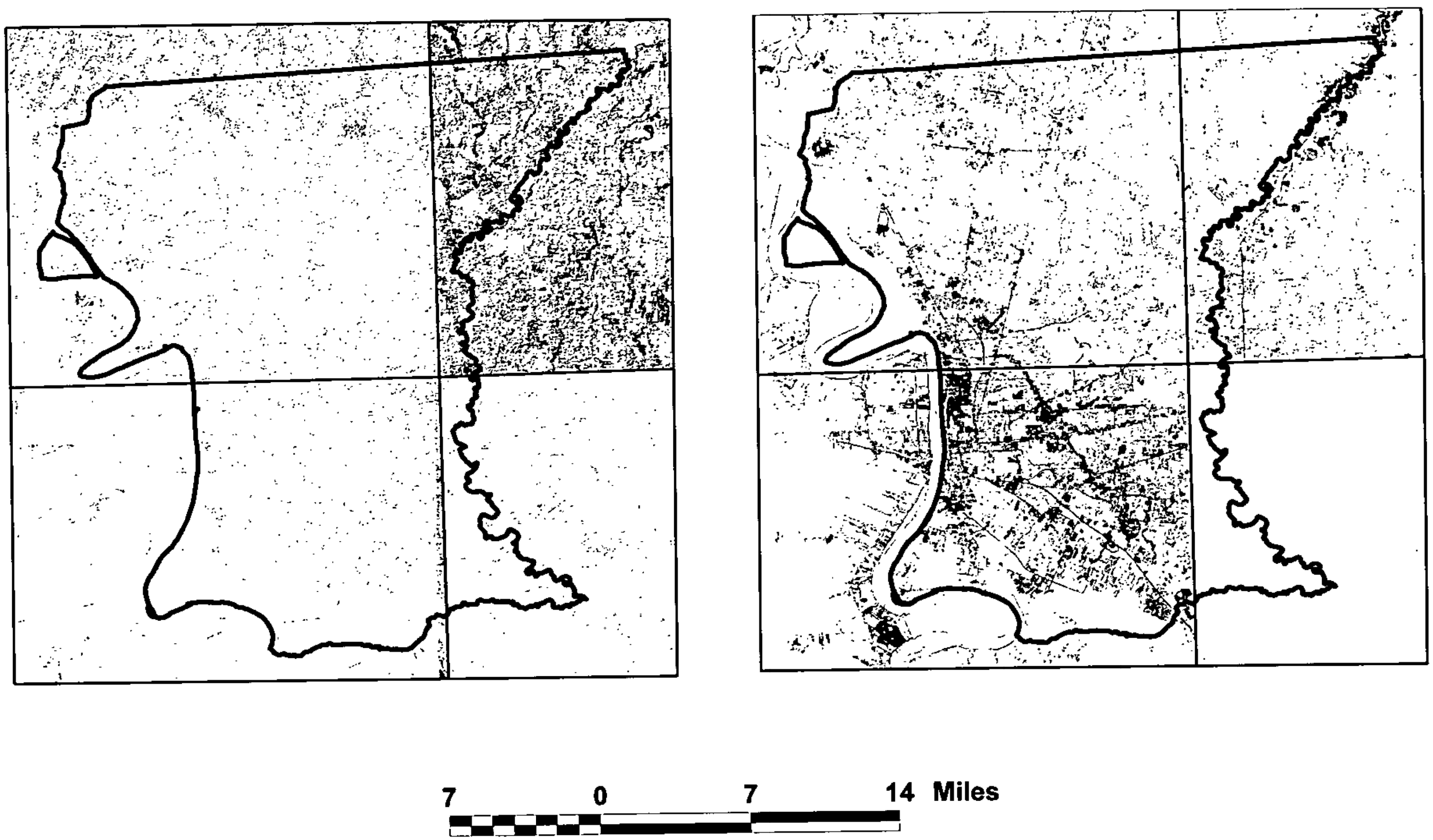


Figure 3. Spectral and radiometric differences in the four panels that comprise the study area.

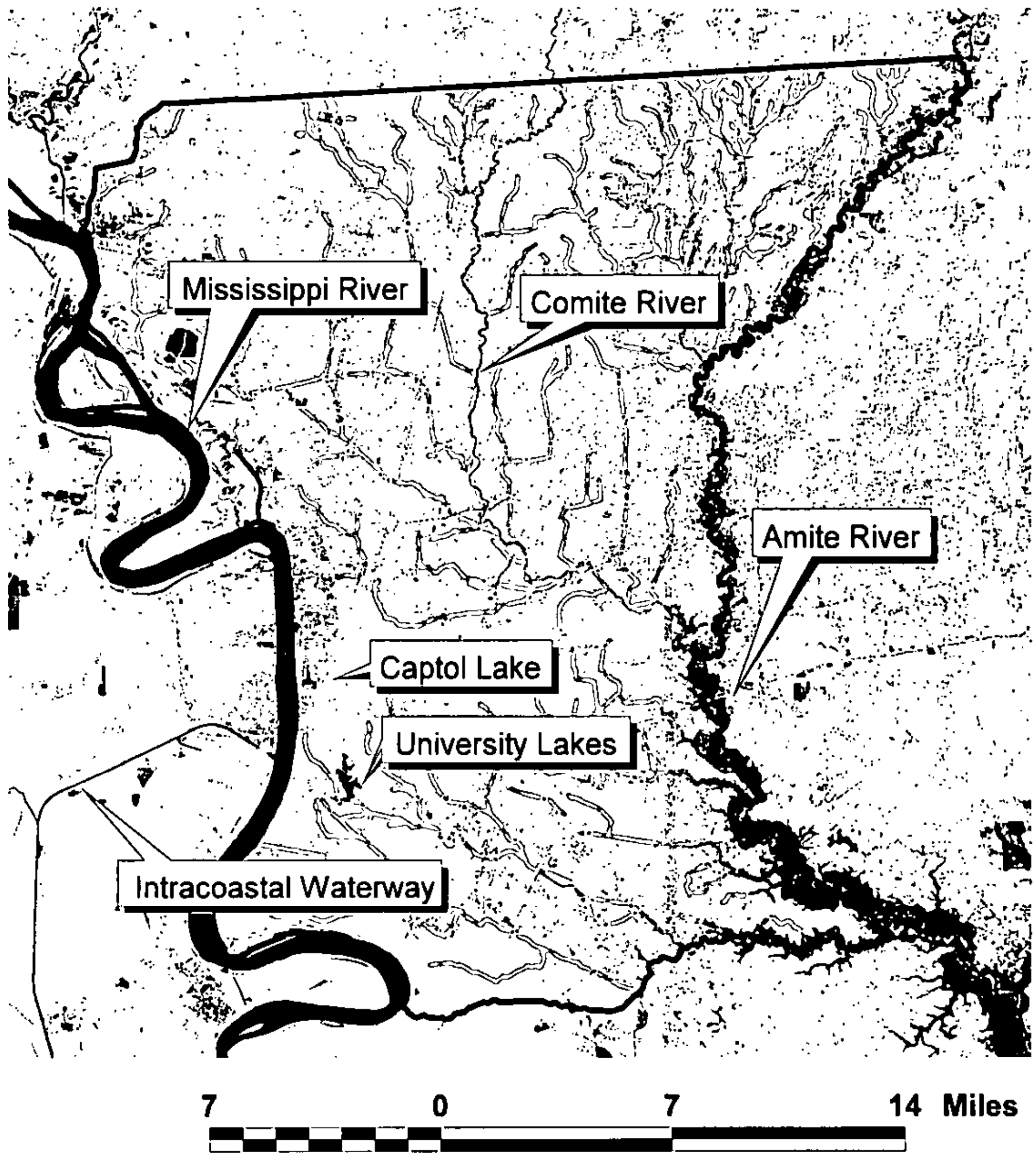


Figure 4. Open water classification results. The yellow lines in this figure are from the USGS, 1:100,000 scale Digital Line Graph hydrography layer.

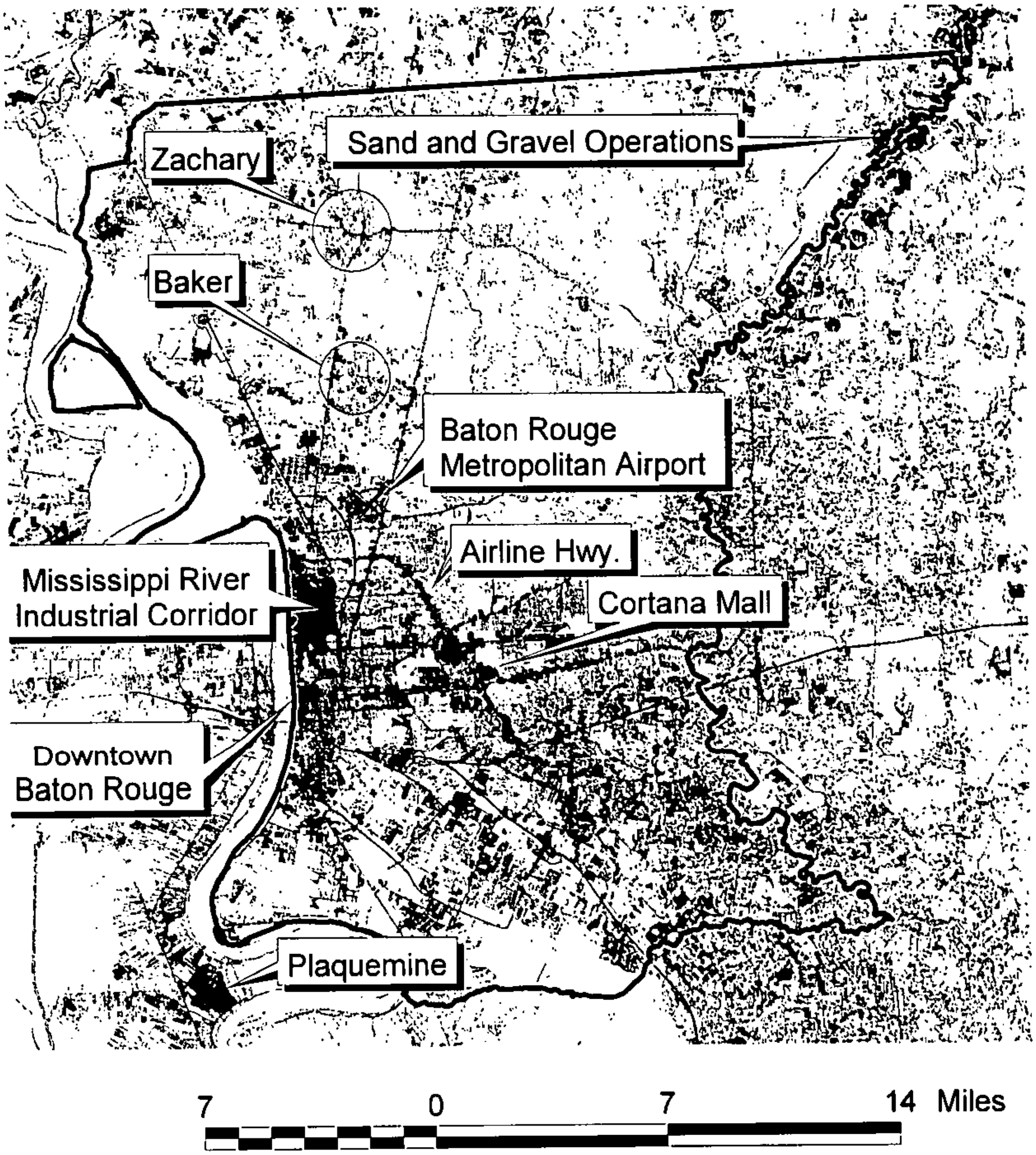


Figure - 5. High reflectance classification results. This category identifies both natural features, such as sandy areas (high infiltration rates), as well as, roads, buildings, and other hard (impervious) surfaces.

The "Hard Surfaces / Sand and Gravel / Rocks" category is a good example of how different ground features can be mixed into a single category. This classification groups very different objects into one class. Buildings, roads, and parking lots are clearly hard surfaces. They are, perhaps, the most striking features displayed in the image. However, the spectral and radiometric signatures of these features are not distinguishable from sand, gravel and rocks exposed on the surface.

Table 5.
Initial Classification Scheme from the SPOT-TM Image

Agriculture
Hard Surfaces / Sand and Gravel / Rocks *
Forest (non-urban)
Forest (rural)
Forest (urban)
Forest (scrub / shrub)
Grass / Agriculture
Grass / Scrub / Shrub
Wetlands
Open Water **

* This feature is mapped in Figure 5.
** This feature is mapped in Figure 4

The hydrologic significance of these features is very different. Hard surfaces represent an important alteration to hydrologic processes in the urban watershed. Natural surfaces, other than rock, do not generally produce direct runoff. Impervious surfaces produce large amounts of direct runoff and exacerbate the problem by requiring drainage systems to move that water directly into adjacent waterbodies. On the other hand, sand and gravel areas exhibit very high rates of infiltration. The two processes must be distinguished in mapping hydrologic functions.

AERIAL PHOTOGRAPHIC ANALYSIS

Because of the limited success using image analysis techniques on the SPOT-TM data, it was decided to use the aerial photographs used to prepare the urban forest canopy data from East Baton Rouge Parish (East Baton Rouge Parish Tree Commission, 1995). After an initial period taking ground-truth surveys and familiarization with local hydrographic features, aerial photographs were used to map riparian habitat and near-stream land uses. The photos represent data at a scale of 1:18,000. This is sufficient to identify the features listed in Tables 1 and 2.

Both riparian habitat and land use at streamside were identified and mapped onto the 1:100,000 scale. The 1:100,000 scale DLG Hydrography (USGS, 2001) data were chosen because of their complete coverage of East Baton Rouge Parish. This data source is not exhaustive and complete in terms of including every creek, bayou, and waterbody of the parish. It does include most of the major waterways at a reasonable level of detail. In some cases, to represent more complete coverage 1:24,000 scale data were integrated into the base data set (USGS, 2001). Each reach was identified and attributed for left and right bank land use and habitat. In the case of reaches that are represented with a separate right and left bank, the mid-stream side of each arc was assigned as water. Lakes and other areal features were not included in this analysis.

Using the aerial photographs, the entire parish was completed in approximately three (3) months. This includes time to perform the photo interpretation, ground truth and verification, and attribution of the digital hydrography. It is estimated that it would take approximately two to three additional months to accomplish the same set of tasks for the 1:24,000 scale data.

RIPARIAN HABITAT AND NEAR-STREAM LAND USE INVENTORY

Once attributed, the hydrography was further processed to develop a topological structure to assist in further analysis. Each arc was examined for direction and cyclic redundancy. To perform network analyses, it is necessary to align all arcs in a downstream fashion. In addition, network processing cannot correctly handle cyclic topology. In these data, this is only a problem in a few locations. For example, Ward Creek has a diversion canal in its lower reaches and a distributary as it enters into Bayou Manchac. Also, the Baker Canal and its related structures significantly alter the hydrography. In its case, it cuts a number of creeks and bayous and crosses several hydrologic divides. Some additional time was spent in the field investigating these relationships and correcting the digitally mapped hydrography.

Once mapped, the operator of the GIS can be enlisted to collect the data for use in hydrologic analysis. An example of this is developed in the next section of this report. In the digital geodatabase, it is possible to identify any set of stream reaches and calculate the cumulative statistics related to near-stream land use and riparian habitat. In a GIS, this is a simple query and can be done by attribute, graphically, or topologically. In the first approach, reaches can be selected using their names, watershed designation, *etc.* The second method allows the GIS user to graphically select stream reaches on the screen. The third method allows a GIS user to identify a specific reach and topologically move upstream or downstream from the location of interest. With the waterbodies of interest selected, statistics can be generated on the total length of its near-stream land use and/or riparian habitat.

It is important to note the absolute linear mileage of these figures is not an accurate depiction of reality. This concept is depicted in Figures 1 and 2. From these, it is clear that neither the 1:24,000 scale, 1:100,000 scale or the image depict the same feature in the same manner. Furthermore, they all have different length for each representation of the same thing. For this reason, the data collected in this report are analyzed using the percent of total bank length in a given watershed.

Total bank length is calculated as the length of the left bank plus the length of the right bank. In most cases, for waterbodies represented as single arcs, these numbers are the same. However, for those reaches that are represented with a left and right bank, these numbers can be quite different. It is also important to indicate that the numbers reflect approximately twice the total length of the actual water body, again depending on whether it is represented by one or two arcs. When examining the data in this report, the reader must keep in mind the actual downstream miles are approximately half of the bank length reported.

Percent land use and riparian habitat is also useful for management purposes. It allows for the comparison of different watersheds of different sized. For example, it is feasible that the proportion of a watershed or riparian habitat within a given watershed is the key factor that determines environmental response. It is also feasible that the juxtaposition and combinations (topology) of various land uses and riparian habitats strongly influence such responses as water quality. The biogeochemical cycles that operates in different riparian habitats function to increase or decrease various measures of water quality (Walbridge and Lockaby, 1994).

For management purposes, using percent land use and/or riparian habitat also provides a means for analyzing the effect of proposed changes in these factors. Although, at present, there are not enough data to develop reliable models of land use, riparian habitat, and water quality; there are clearly observable relationships between these. As more water quality data are collected these models can be developed. At that point, predictive models can be used to evaluate various management alternatives. A more complete discussion of this appears in the next section.

Figures 6 and 7 depict the near-stream land use and riparian habitat data in the Ward Creek watershed. A complete inventory for East Baton Rouge Parish Basin Groups can be seen in Appendix C, as maps (Figures C-1 – C-10).

Table 6 shows the mix of land use and habitat in the uppermost reaches of the Ward Creek watershed, from where it crosses Clay Cut Road. The site was selected as a representative of typical headwater, watershed in the older, longer developed areas of Baton Rouge. This is predominantly an urban forest watershed with a large proportion of residential and commercial land uses combined with concrete lined streambeds. These combinations represent approximately 80% of the total bank length of Ward Creek.

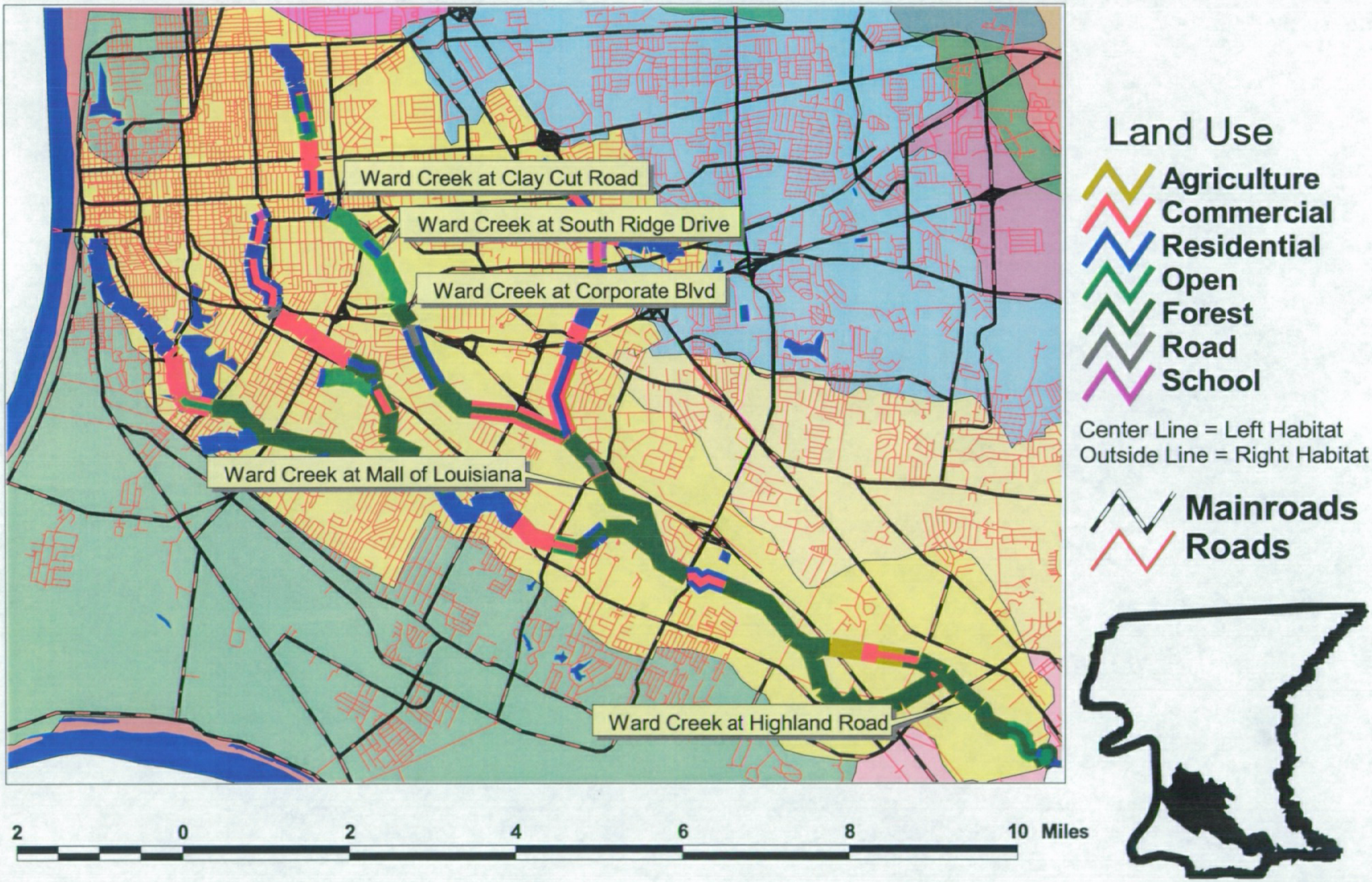


Figure 6. Near-stream land use of Ward Creek

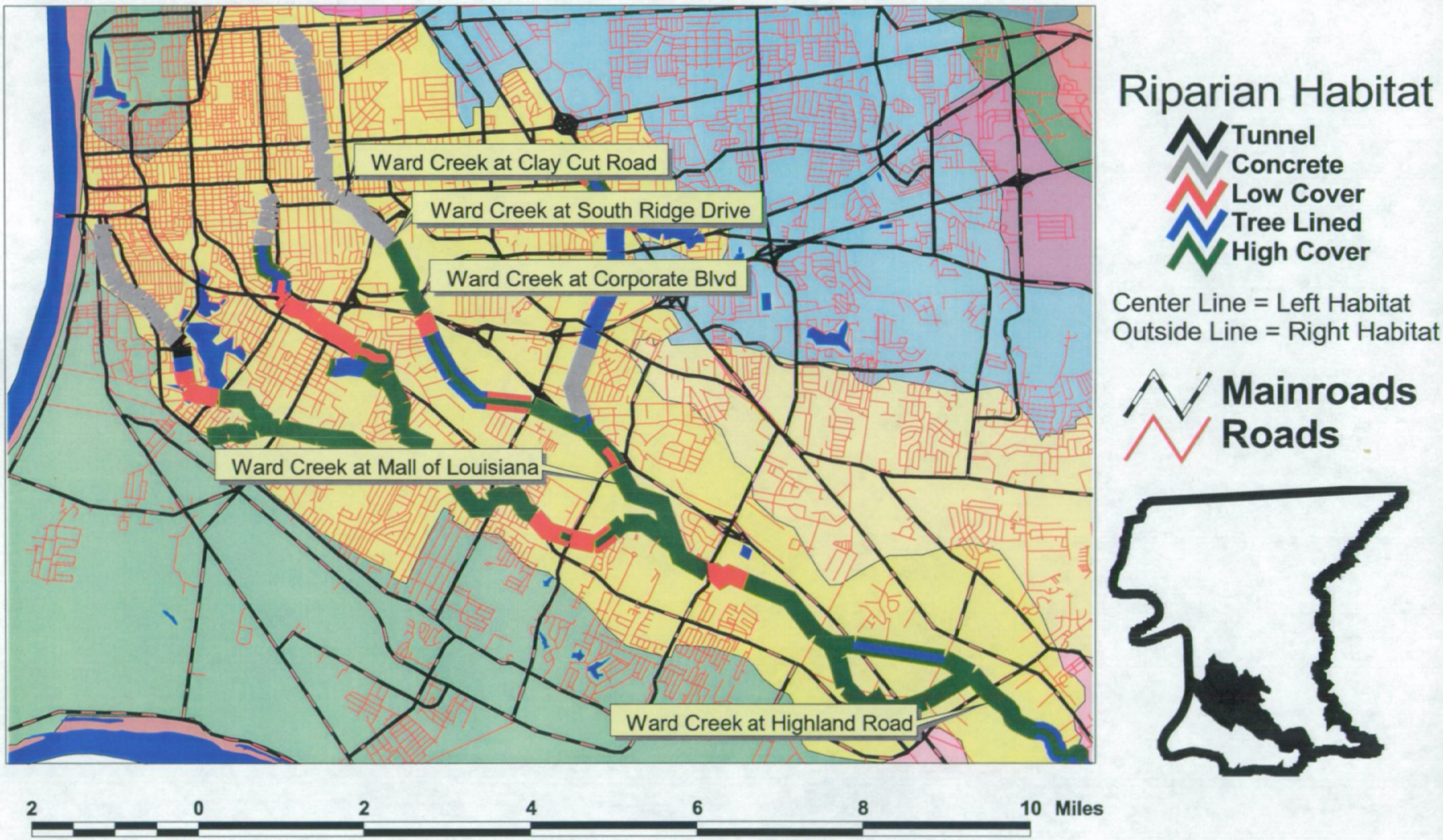


Figure 7. Riparian habitat of Ward Creek

Table 6.
Near-stream Land Use and Riparian Habit on Ward Creek Above Clay Cut Road

Percent Total Bank Length	Land Use	Habitat
34.22	Residential	Concrete
24.72	Commercial	Concrete
20.05	Commercial	Tunnel
8.44	Open	Concrete
4.27	Residential	Tunnel
3.69	Forest	Closed canopy
3.34	Road	Tunnel
1.27	Forest	Tunnel

NOTE: Bank length is the total of both left and right bank lengths.

The basin above South Ridge Drive defined the second section of the watershed. This point is immediately south of the municipal golf course, at Webb Park. It was selected as the point where the concrete-lined segments of Ward Creek end. Geologically, the concrete terminates just above the fault zone for the Baton Rouge fault. At this point the channel is deeply incised into the terrace and opens into a relatively natural area, bellow the fault. According to the 1:100,00 scale map, this location is approximately 0.79 miles from the first sampling point, but was selected because of its location at the end of the concrete bed and its location immediately bellow the golf course.

The mix of land use and riparian habitat, at this point in the watershed (Table 7), only show one significant change. The golf course makes the land use class, Open, nearly 22 percent of the watershed. However, the riparian habitat remains predominantly concrete.

Table 8 displays the land use and habitat mix for the next downstream watershed. This reach terminates at the point where Ward Creek crosses Corporate Boulevard. From the 1:100,000 scale map, this is approximately 0.65 miles downstream from the second sample location. The additional distance runs through open space. However, this area is rapidly developing and the area near the end of this segment is currently being cleared and developed.

The mix of land use and habitat for the basin upstream of this point reflects the additional open space. As a result, the changes in relative frequency show a new class of Open and Closed canopy. This concomitantly reduces the proportion in the top five classes, upstream.

**Table 7.
Near-stream Land Use and Riparian Habitat
on Ward Creek Above South Ridge Drive**

Percent Total Bank Length	Land Use	Habitat
30.93	Residential	Concrete
21.63	Open	Concrete
20.45	Commercial	Concrete
16.59	Commercial	Tunnel
3.53	Residential	Tunnel
3.06	Forest	Closed canopy
2.77	Road	Tunnel
1.05	Forest	Tunnel

NOTE: Bank length is the total of both left and right bank lengths.

**Table 8.
Near-stream Land Use and Riparian Habitat
on Ward Creek Above Corporate Boulevard**

Percent Total Bank Length	Land Use	Habitat
27.10	Residential	Concrete
18.95	Open	Concrete
17.92	Commercial	Concrete
14.53	Commercial	Tunnel
12.37	Open	Closed canopy
3.09	Residential	Tunnel
2.68	Forest	Closed canopy
2.42	Road	Tunnel
0.92	Forest	Tunnel

NOTE: Bank length is the total of both left and right bank lengths.

Table 9.
Near-stream Land Use and Riparian Habitat on Ward Creek above Bluebonnet Road

Percent Total Bank Length	Land Use	Habitat
16.77	Residential	Tree lined
14.74	Forest	Closed canopy
11.97	Residential	Concrete
9.22	Commercial	Concrete
6.85	Open	Concrete
6.66	Residential	Closed canopy
5.36	Commercial	Closed canopy
5.28	Commercial	Tree lined
4.92	Commercial	Tunnel
4.19	Open	Closed canopy
3.74	Commercial	Low vegetation
2.11	Road	Low vegetation
1.64	Forest	Tree lined
1.07	Residential	Low vegetation
1.06	Road	Tunnel
1.05	Residential	Tunnel
1.02	School	Low vegetation
0.65	School	Tree lined
0.58	Forest	Concrete
0.47	Forest	Low vegetation
0.31	Forest	Tunnel
0.21	Road	Concrete
0.13	Open	Tree lined

NOTE: Bank length is the total of both left and right bank lengths.

The next reach was sampled at a spot immediately south of Bluebonnet Boulevard, next to the Mall of Louisiana. At this point Ward Creek is a relatively deep channel with a flat bottom and a trapezoidal shape, with at lease two terraces. Table 9 depicts the land use and habitat classes for the upstream watershed.

The important feature of this reach of Ward Creek is that it passes through a great deal of urban forest. This is reflected by the fact that 55 percent of the watershed is in Closed canopy or Tree lined habitats. The predominant land use classes are Residential with 37.5 percent and Commercial with 28.5 percent. Slightly less than 29 percent of the near-stream land uses are classified as Forest or Open. The total length of the 1:100,000 scale hydrography indicates and approximate three-fold increase in stream miles in this sampling site compared to the previous sample point. The North Branch of Ward Creek represents much of the increase.

The final location in this study was located immediately downstream from the point Highland Road crosses over Ward Creek. The 1:100,000 scale hydrography indicates that the watershed above this sample point more than doubles that of the previous sample site. Much of the increase is reflected in the addition of Dawson Creek and Bayou Duplantier watersheds, downstream from the previous sample site.

This sample location is close to the end of Ward Creek and continues southwest, through the Santa Maria golf course and the State Fairgrounds to the confluence with Bayou Manchac.

Table 10 represents the near-stream land use and riparian habitat for the final sample location. The predominant near-stream land use is forest along the banks of the watershed above Highland Road. It represents over one-third of the entire bank length of this waterbody. Residential has the second largest proportion, with nearly 30 percent of the total bank length. Slightly more than one-fifth of the total bank length land use is commercial in nature. The riparian habitat is even more striking in its relative proportions. Forest land use is the most represented with over half of the stream reaches represented in this class. An additional 13.5 Percent are represented as tree lined. That is over 65 percent of the total bank length in urban forest habitats. Great deals of these urban forest stream miles come from the Dawson Creek and Bayou Duplantier watersheds that join Ward Creek south of the Mall of Louisiana. Concrete is slightly less than one-fifth of the watershed habitat classifications. Again, the upper reaches of Dawson Creek and Bayou Duplantier contribute a large amount of these miles. The low vegetation classification represents almost 13 percent of the total bank length of this watershed.

MACROINVERTEBRATE-BASED WATER QUALITY ASSESSMENT

A synoptic survey of stream macroinvertebrates was performed on July 31, 2001. The weather was clear and sunny. Temperatures were on the rise from a daily high of 85 degrees a week earlier to 93 degrees, that day. There had been little or no rain for the past 10 days. Streamflow had receded to near baseflow conditions since Tropical Storm Allison in early June. That event had generated record flows and scoured-out the channel. The strength of the macroinvertebrate method of assessing is its ability to depict a time-averaged portrayal of water quality. However, when sampled in isolation, it suffers from the same problems as dip-samples that are analyzed for chemical agents. That is a single, recent event can strongly

Table 10.
Near-stream Land Use and Riparian Habitat on Ward Creek above Highland Road

Percent Total Bank Length	Cumulative % Length	Land Use	Habitat
36.04	36.04	Forest	Closed canopy
10.29	46.33	Residential	Concrete
9.72	56.05	Residential	Closed canopy
7.57	63.62	Commercial	Low vegetation
6.93	70.55	Residential	Tree lined
4.10	74.65	Commercial	Tree lined
4.05	78.70	Commercial	Concrete
3.16	81.86	Commercial	Closed canopy
2.74	84.60	Open	Concrete
2.55	87.15	Commercial	Tunnel
2.38	89.53	Open	Closed canopy
1.73	91.26	Open	Low vegetation
1.67	92.93	Residential	Low vegetation
1.48	94.41	Road	Low vegetation
0.99	95.40	Open	Tree lined
0.90	96.30	Agriculture	Closed canopy
0.66	96.96	Forest	Tree lined
0.51	97.47	Agriculture	Tree lined
0.43	97.90	Road	Tunnel
0.43	98.33	Residential	Tunnel
0.42	98.75	Forest	Low vegetation
0.42	99.17	School	Low vegetation
0.28	99.45	School	Tree lined
0.25	99.70	Forest	Concrete
0.15	99.85	School	Concrete
0.15	100.00	Forest	Tunnel

NOTE: Bank length is the total of both left and right bank lengths.

influence the results. In this case, the final sample location was highly influenced by a violation of siltation controls at an upstream construction site. The following results demonstrate how this effects the interpretation of the data.

The first site, Ward Creek at Clay Cut Road, is a location that is completely concrete lined, upstream. The water quality reflects the influence of this riparian habitat. It showed little species diversity (see Table 11). There was only one somewhat sensitive species, with a small

Table 11.
Macroinvertebrate Index
for Ward Creek at Clay Cut Road

Species Class:

Somewhat Sensitive		Tolerant	
Sample Class	Species	Sample Class	Species
A	Beetle Larvae	C	Midge Larvae
		A	Pouch & Pond Snails

Water Quality Index = 4
Water Quality Class = Poor

NOTE: Sample Class refers to the class assigned to the sample, based on the number of individuals collected (A = 1 to 9, B = 10 to 99, C = 100 to 999, *etc.*).

sample size. Although there were just two tolerant species, there was a large number (> 100) of Midge Larvae. These factors combined to generate a score of 4, for a poor rating.

The second site, South Ridge Drive, was chosen because it is located at the end of the concrete lined section of Ward Creek. The concrete section closely resembled the Clay Cut site and was not assayed. Just bellow the concrete, the creek cuts across the Baton Rouge Fault and lies in a relatively deep channel, until it leaves the fault zone. The banks are tree lined and natural while the channel contained concrete blocks and other trash and debris. The macroinvertebrate index was substantially improved (see Table 12).

The survey shows an increase of species diversity from three to eight. More importantly, the number of somewhat sensitive species went from one to three. The effect of this is to increase the score from this class of macroinvertebrates from two to six. Added to this are the tolerant species, which increase from two to five. This site clearly supported much more diversity than the concrete habitat that was located only a few meters away. In contrast to the concrete lined area (average depth .3 feet), this portion of Ward Creek has deep pools that held a much larger volume of water. The concrete channel, at the time of sampling, was much shallower and relatively more "sterile" than the natural, tree-lined banks, immediately downstream.

Table 12.
Macroinvertebrate Index
for Ward Creek at South Ridge Drive

Species Class:

Somewhat Sensitive		*Tolerant*	
Sample Class	Species	Sample Class	Species
A	Damselfly Larvae	A	Aquatic Worms
A	Crane Fly Larvae	B	Midge Larvae
B	Dragonfly Nymphs	A	Leeches
		A	Pouch & Pond Snails
		A	Other Snails

Water Quality Index = 11
Water Quality Class = Fair

NOTE: Sample Class refers to the class assigned to the sample, based on the number of individuals collected (A = 1 to 9, B = 10 to 99, C = 100 to 999, *etc.*).

At the third sampling site, Corporate Boulevard, two samples were taken, one above the bridge and one bellow the bridge. It should be noted that this site is located in an area that is experiencing much development and there has been a great deal of tree clearing in the area immediately upstream from this site. Although the water was clear at the time samples were taken, within a week, the water was muddy and a nearby constructions site was pumping sediment-laden water from a retention pond directly into the waterbody.

Since there had been no substantial rain in almost two weeks, there was little evidence of such activity. However, stream bottoms exhibited a large amount of fine silt material. The possibility remains that earlier episodes of sediment loads could have influenced the stream health, as measured by the macroinvertebrate index. Despite the outward appearance, this site showed a decrease in water quality from the South Ridge Drive site. Tables 13 and 14 show a decrease in the number of species, with nearly half the number of tolerant species. The number of somewhat tolerant species remains the same as South Ridge Drive in the upstream sample, while dropping from three to two downstream. Macroinvertebrate indices drop, concomitantly, to nine and seven, respectively. These both represent classification as poor quality water.

Table 13.
Macroinvertebrate Index
for Ward Creek at Corporate Boulevard
Upstream from the Bridge

Species Class:

Somewhat Sensitive		*Tolerant*	
Sample Class	Species	Sample Class	Species
A	Crawfish	A	Aquatic Worms
A	Damselfly Nymphs	A	Midge Larvae
A	Dragonfly Nymphs	A	Pouch & Pound Snails

Water Quality Index = 9
Water Quality Class = Poor

NOTE: Sample Class refers to the class assigned to the sample, based on the number of individuals collected (A = 1 to 9, B = 10 to 99, C = 100 to 999, *etc.*).

The final spot sampled was located several hundred yards downstream from the Bluebonnet Road bridge over Ward Creek, near the Mall of Louisiana. While traveling to that site, it was conserved that the water had become muddy, somewhere between the point that Interstate-10 crosses Ward Creek and the Essen Lane bridge. The macroinvertebrate index reflects further degradation in water quality (see Table 15).

Steep banks characterize this site with a terrace on the south side. Vegetation is a tall tree on both sides. The site is located approximately 100 yards downstream from the Mall of Louisiana storm drain, a 60-inch pipe. The number of species was reduced from the upstream sites that resulted in only maintenance of the poor rating of nine. However, the number of somewhat tolerant species was higher and there was only one tolerant species. This could be an artifact of the muddy water and a reflection of recent water quality degradation.

An attempt was made to sample a site near the bottom of the watershed, near Santa Maria, where Ward Creek joins with Bayou Manchac. However, the channel banks were too steep and inaccessible by foot. In addition, the waters were completely occluded by the sediment load they carried. The water quality was, clearly, poor and any samples would have been skewed by these conditions. For these reasons, it was decided not to sample at this site.

Table 14. Macroinvertebrate Index for Ward Creek at Corporate Boulevard Downstream from the Bridge

Species Class:

Somewhat Sensitive		*Tolerant*	
Sample Class	Species	Sample Class	Species
A	Crawfish	A	Aquatic worms
B	Damselfly Nymphs	A	Pouch & Pound Snails
		A	Other Snails

Water Quality Index = 7
Water Quality Class = Poor

NOTE: Sample Class refers to the class assigned to the sample, based on the number of individuals collected (A = 1 to 9, B = 10 to 99, C = 100 to 999, *etc.*).

Table 15. Macroinvertebrate Index for Ward Creek at Bluebonnet Boulevard

Species Class:

Somewhat Sensitive		*Tolerant*	
Sample Class	Species	Sample Class	Species
A	Crawfish	A	Leeches
A	Damselfly Nymphs		
A	Dragonfly Nymphs		
A	Clams		

Water Quality Index = 9
Water Quality Class = Poor

NOTE: Sample Class refers to the class assigned to the sample, based on the number of individuals collected (A = 1 to 9, B = 10 to 99, C = 100 to 999, *etc.*).

WATER QUALITY AND WATERSHED CHARACTERISTICS RELATIONSHIPS

The water quality analyses and watershed inventories provide an opportunity to examine the relationship between water quality and watershed characteristics. These interrelationships are difficult to quantify, but it is a basic premise of watershed hydrology that land use significantly determines watershed responses and water quality (Mitchell, 1991; Leitch and Harbor, 1999). These relationships are difficult to quantify and the interactions are complex and nonlinear in nature. A single sample is not sufficient to model these processes. However, the observed data are instructive in some of the patterns.

Figure 8 shows no clear relationship between the proportion of land uses and the water quality index. Initially, it appears that open space has a large positive effect, and then is less influential. High initial values of residential and commercial land uses appear to have little effect on the peak in water quality index. Farther down the watershed, these proportions level off and drop slowly, while the index takes a moderate rise. Much of this behavior is not intuitive nor does it follow the patterns observed in previous work (Wang, *et al.*, 2000).

Unlike land use, riparian habitat demonstrates a more coordinated relationship with the water quality index (see Figure 9). Initially, concrete and tunnel habitats appear to dominate the pattern. Then, as they fall, increasing proportions of closed canopy appear to contribute to the rise in the index.

In interpreting both of these relationships, it is important to note that the sample was probably influenced by recent episodes of high sediment loads. Silt deposits were evident, presumably from the construction site above Corporate Boulevard. After Ward Creek passed under Interstate-10, before it reached the bridge at Essen Lane, it was muddy and full of sediment, again. These observations make it difficult to interpret these data as a base-line sample. However, it does make it instructive as how this type of reconnaissance can be used to identify negative water quality impacts.

Figures 10 and 11 document the change in number of individuals collected and the number of different species collected change with position in the watershed. In Figure 10, the number of individuals from the tolerant species is very high and drops off, markedly, as the habitat changes from concrete to natural streambed. Concomitantly, the somewhat tolerant species numbers rise, as does the water quality index, as the streambed morphology changes. Numbers continue to decrease, for both groups, in the reaches below the sediment-affected area.

The number of species in each class also shows an interesting pattern. In Figure 11, it appears that the macroinvertebrate water quality index is strongly influenced by the number of somewhat sensitive species present in the sample. Despite the increase in the number of tolerant species between the Clay Cut Road site and South Ridge Drive, the somewhat tolerant species create a higher index value. At Corporate Boulevard, the number of tolerant species

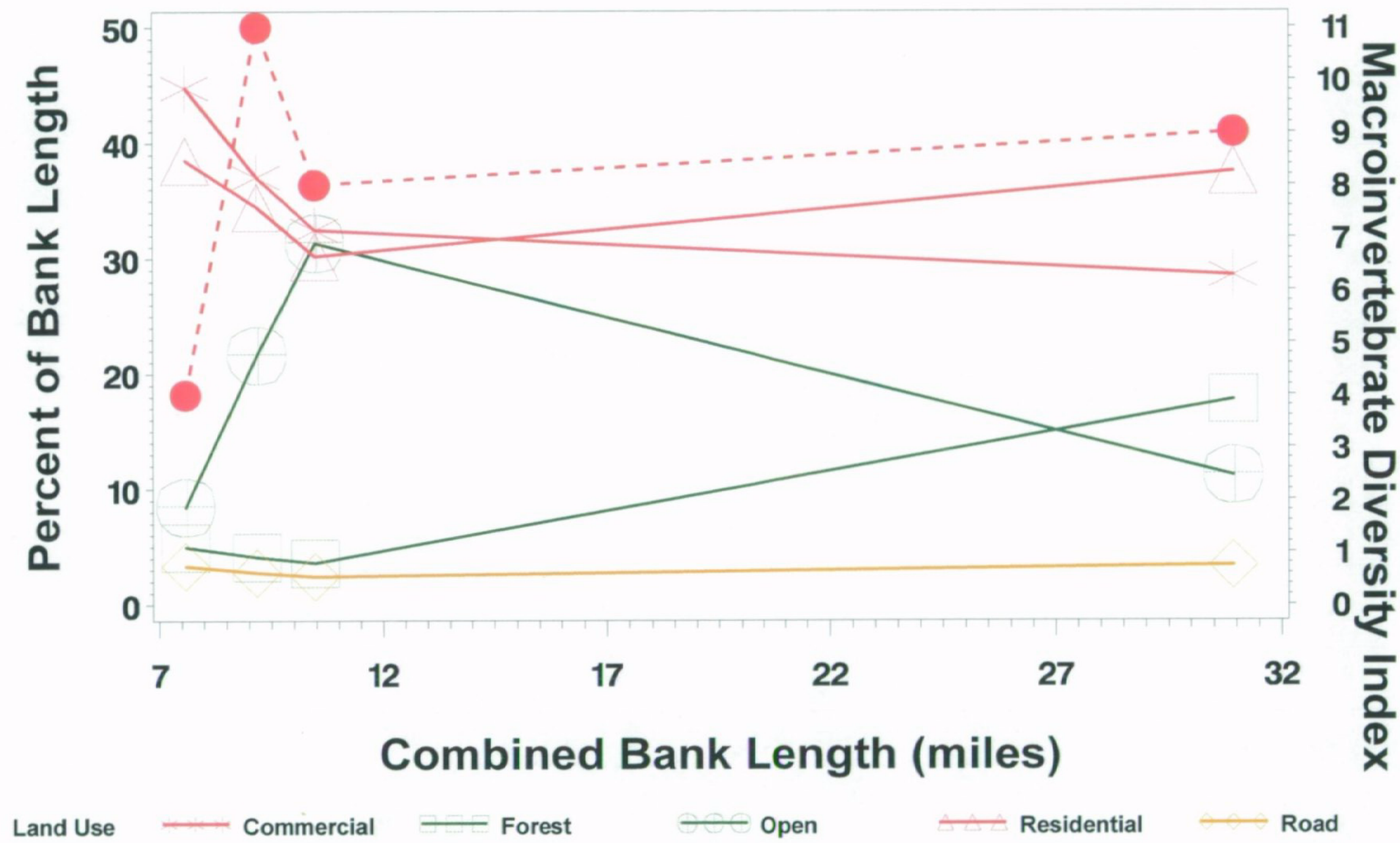


Figure 8. Percent of near-stream land use and water quality index along Ward Creek. The dotted red line represents the calculated Macroinvertebrate Diversity Index.

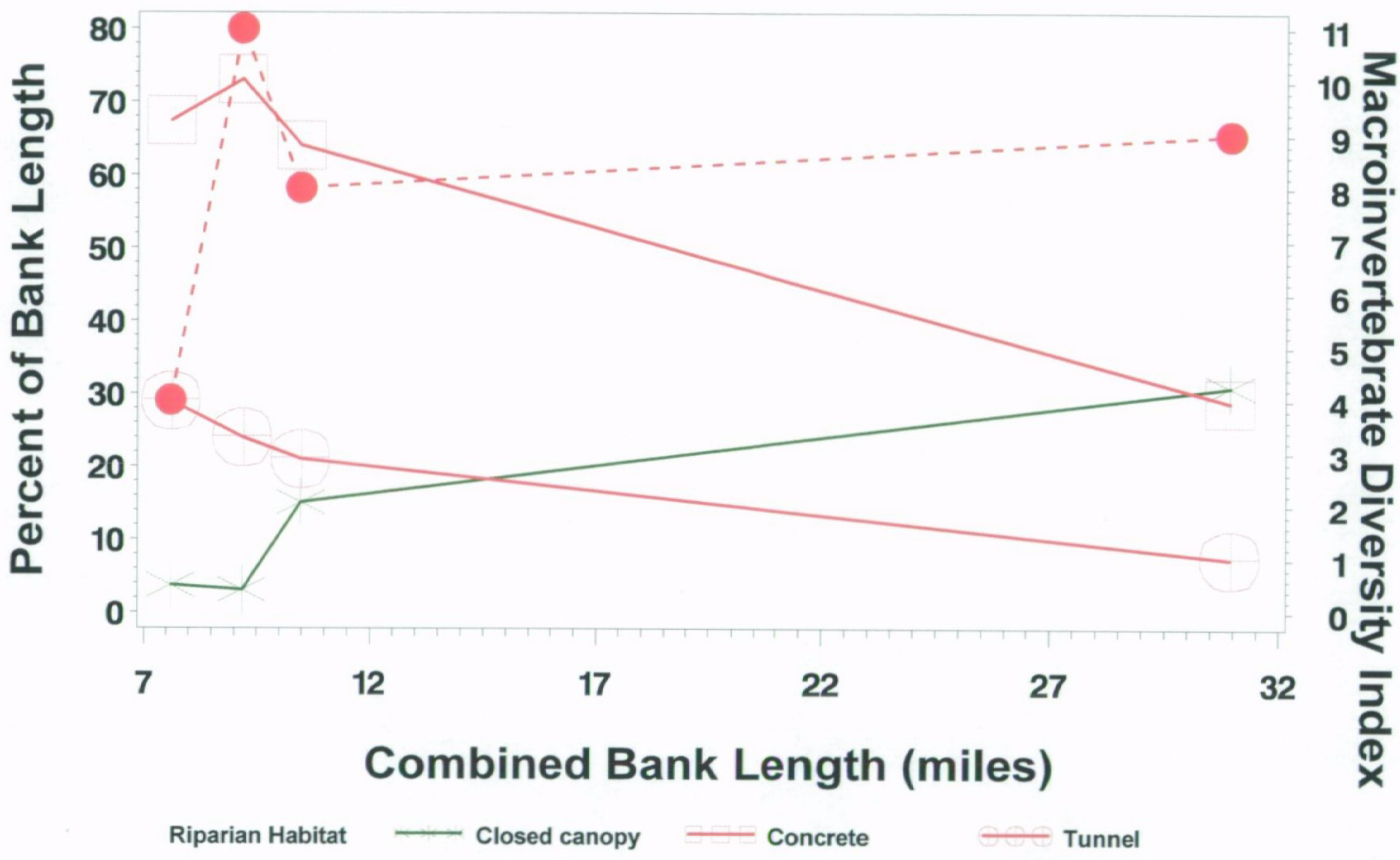


Figure 9. Percent of riparian habitat and water quality index along Ward Creek. The dotted red line represents the calculated Macroinvertebrate Diversity Index.

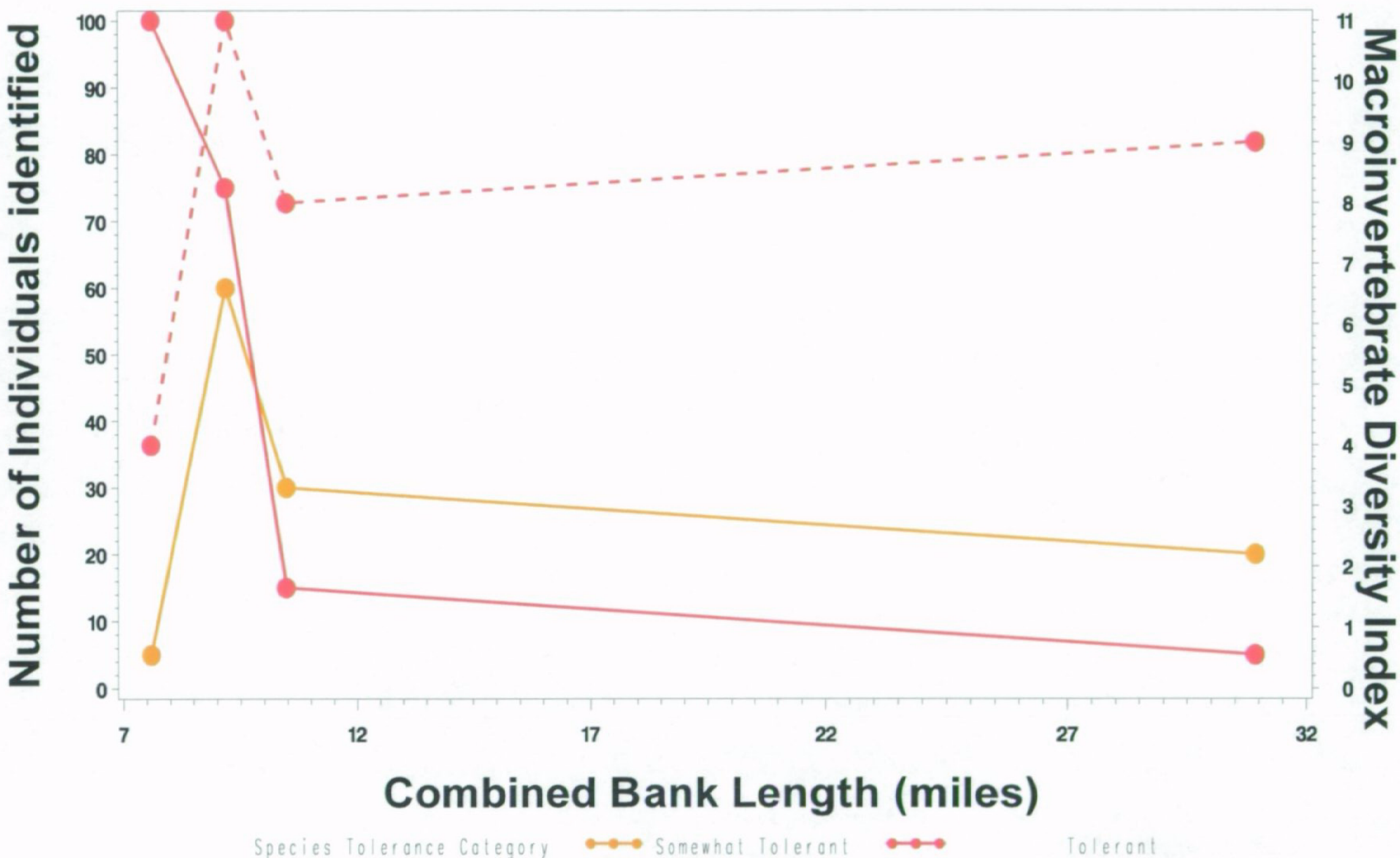


Figure 10. Number of macroinvertebrate specimens collected and water quality index along Ward Creek. The dotted red line represents the calculated Macroinvertebrate Diversity Index.

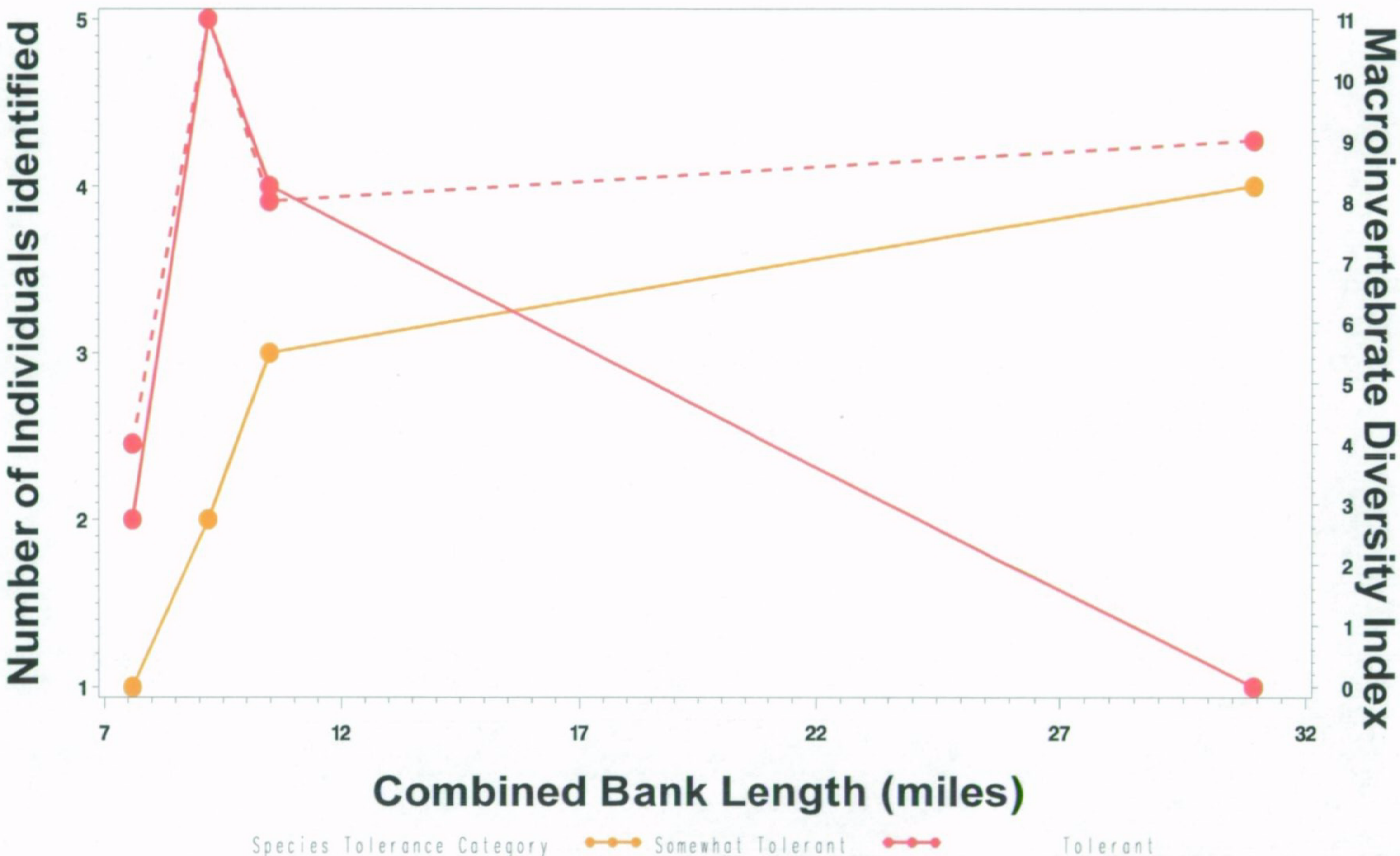


Figure 11. Number of macroinvertebrate species collected and water quality index along Ward Creek. The dotted red line represents the calculated Macroinvertebrate Diversity Index.

drops, precipitously. In the same reach, the number of somewhat sensitive species increases and forces the water quality index to rise.

It is interesting to note that in the muddy section of Ward Creek, the number of somewhat sensitive species increases, while the number of tolerant species drops. The number of species are measures of diversity and are the basis of the index. Somewhat sensitive species are weighted heavier than tolerant species and create a small rise in the index. On the other hand, the observed number of specimens from each class drops in the same reach. This may be the kind of response that would be expected from a relatively recently degraded water body.

SUMMARY

Riparian habitat identification from the SPOT-TM image cannot be automated from existing data. The mixtures of time frames within tiles of the SPOT-TM image will not support analyses in areas that cross the panel boundaries. This also calls into question any analyses within a panel where the SPOT and TM image are not samples within a relatively short period of time. Such an analysis may be performed with extensive handling of the data and "head's up," hand digitizing off the image. Using areal photographs and mapping features to registering detailed vector data is a much more effective approach.

The importance of context in distinguishing features of different hydrologic functions is clearly important. Features of similar spectral and radiometric characteristics but differing hydrologic function must be uniquely identified. Hard surfaces and sand and gravel appear indistinguishable after analysis. This is a good example of one of the problems encountered in this analysis.

For hydrologic mapping purposes, temporal sampling differences create a substantial impediment to using the SPOT-TM data for mapping. The differences in land cover resulting from natural variability in precipitation and temperature can be significant. To keep the data consistent, images must be matched in both space and time. This is a significant problem when large areas are retrieved from the extensive archives of satellite data. Matching clear days with passes of different sensing platforms is not a trivial exercise. Nevertheless, data from both the SPOT and Landsat (TM) platforms should be matched as close in time as possible.

The aerial photographic interpretation and mapping to vector data was the most effective approach to mapping riparian habitat. The resolution of the photography was sufficient to clearly identify the various feature classes of interest to this study. The approach has limitations in that the vector data must be present to be able to assign attributes to it. However, "heads-up" digitizing can be done on scanned, registered and rectified photographs to add arcs that are not present in the existing data. This was done on several occasions. Another approach is to select arcs from another source and place them in the analysis coverage. This was also done. Unfortunately, these approaches can introduce additional error an analysis and might represent data from a different scale. However, for most applications this represents the best available technology and data and is the only option, short of starting from scratch and digitizing the entire study area.

The riparian habitat and near stream land use mapped using the aerial photographs were used in a macroinvertebrate study of the Ward Creek watershed. With only one sample in time, it is difficult to make definitive statements. However associations were clear with respect to the types of macroinvertebrate present in Ward Creek at four divergent points along the length of the watershed. Indeed, a local violation of nonpoint pollution was in process from a local construction site. Its effect on the waterbody was evident in the number of macroinvertebrates collected and the diversity of species, as well as, the water quality index.

CONCLUSIONS

MAPPING HYDROGRAPHIC FEATURES

Identification of stream hydrology and associated riparian habitat was not successful using the SPOT-TM imagery. A major factor in this is the small cross-section of streams found throughout the parish. The riparian habitat associated with the small streams did not have sufficient dimensions to produce an identifiable spectral and radiometric response. From a remote sensing classification perspective, small streams and adjacent riparian areas are difficult to resolve spatially, spectrally, and radiometrically. Wickware and Howarth (1981) suggest that pixel-by-pixel analysis of linear features is problematic due to frequent boundaries between classes. In this study, only relatively large waterbodies were clearly classified. This suggests that the initial concept was valid. However, an interaction between the area and perimeter of features and the resolution of the remote sensing data made it impossible to reliably map the desired features. How these factors interact influences their ability to be identified without operator intensive, heads-up analysis.

The spatial resolution of the SPOT part of the SPOT-TM image is ten (10) meters (32.8 feet). Each pixel represents 100 square meters (~1076 square feet). This is the minimum area an object must have in order to be individually distinguished. However, the spatial resolution of the TM part of the image is 30 meters (~98 feet). A TM pixel is therefore, ~9687 square feet. The TM part of the SPOT-TM merged image provides the spectral resolution to distinguish natural features. Thus vegetation assemblages must have a minimum size of 98^2 square feet. As a result, the 10-meter resolution of the SPOT part of the merged image does not provide sufficient resolution to distinguish adjacent riparian habitat areas with small cross-sections.

These results suggest that mapping drainage networks cannot be easily automated. To the human eye, drainage patterns are clearly identifiable on the image. Analytical techniques are not sophisticated enough to duplicate this task. Spatial context and *a priori* knowledge of an area are indispensable actors in classifying a pixel. Chidley and Drayton (1986) found that the identification of streams on the basis of spatial characteristics alone was inefficient. They found the use of thematic information was "beneficial." Clearly, the use of ancillary data is important in mapping hydrographic features. Current mathematical methods cannot duplicate these functions, as performed by the human eye.

Ultimately, any mapping system devised must be able to distinguish between geomorphological features while simultaneously identifying features of differing hydrologic function. It is not sufficient to end up with a classification that cannot distinguish between important factors such as sand and gravel (high infiltration rates) and hard surfaces (impervious, no infiltration). Figure 5 clearly depicts this problem. It is possible, if adequate vector data were available, to discriminate between sandy streambeds and parking lots, roads and other impervious surfaces.

Radiometric distinction of streams and riparian areas also posed problems. Radiometric identification of features is based on the quantification of the intensity of emitted radiation. The ability to distinguish specific reflected radiation is influenced by the size of the area reflecting that radiation (Avery and Berlin, 1992). A clear example of this is the strong reflectance provided by concrete. Concrete features appear very bright in the image. Likewise, sandy and stone covered water bottoms also appear as bright features.

Aerial photography mapped to existing vector data was a very successful alternative to other data dependent or labor-intensive methods. It also has the added benefit of not requiring extensive image registration and rectification. Furthermore, because the data are mapped to existing spatial features, spatial alignment problems are minimized. That is, the new data will match with existing data. By using existing lines or polygons, road networks and land parcels are already accurately located.

The macroinvertebrate sample and its resulting water quality index present a paradox. A single, synoptic, sample is of relatively little use for water quality management. However, this particular sample was indicative of an existing water quality problem and demonstrates the utility of this approach as part of an integrated, long-term strategy for environmental management.

The single sample is too small, in space and time, to make reliable inferences about land use, riparian habitat, and water quality. Spatially, at least one more sample near the end of the watershed would have been preferable. Temporally, repeated measurements at the locations, over all four seasons and a period of several years would better identify and define the relationships. It is likely that some of the observed relationships are merely spurious assemblages of four data points. Likewise, some unmeasured seasonal factor may be operating that cause the points to appear random.

Another sample could change these conclusions; repeated samples should demonstrate a pattern. Because of the diversity of life history strategies of invertebrates, it would not be expected that all these species would be present, year-round. Figures 10 and 11 demonstrate how a pattern starts to form, consistent with expectations, and then is interrupted. Signs in the Corporate Boulevard sample indicated recent siltation. Stream bottoms appeared to have had relatively recent deposits. At the same time, the number of specimens dropped and species diversity was depressed. The result was a lowered water quality index. The observation that the number of somewhat sensitive species increases after Corporate Boulevard suggests increasing water quality. But the water over that reach was muddy at the time of sampling.

This destroys the utility of this sample as a baseline sample of "normal" conditions. But it points out its great utility in identifying cotemporaneous or recent problems. After observing the water quality problem. It was reported to local authorities. The next week a citation was issued to a construction site immediately upstream from the Corporate Boulevard sampling location. The operator was pumping sediment-laden water from a detention pond, directly into Ward Creek.

The longitudinal analysis of land use and riparian habitat suggest that near-stream land use does not highly influence water quality (Figure 8). However, the interaction between various riparian habitats does appear to correlate with the index values (Figure 9). This implies one of two possible scenarios.

1. Riparian habitat on the stream bank and along the water bottom act as a filter for waters that run off the watershed.

2. Near –stream land use is irrelevant to water quality because storm sewers bypass it.

Both of these factors seem reasonable and probably exist simultaneously in the watershed. This is an example of the complex interactions that function to govern a watershed's response characteristics.

There were no statistically significant relationships between the calculated macroinvertebrate water quality index and various classes of land use or riparian habitat. However, both the number of individual specimens collected and the number of different species observed, exhibited significant correlations with some of these factors. Figures 12 – 18 show the most significant of these relationships.

The number of tolerant individuals correlates, negatively, with the number of miles of open land use along the stream bank ($r = -0.9778, p < 0.0222$). This is displayed in Figure 12. This decrease in the number of individuals from tolerant species indicates that as near-stream open space increases the water quality increases. Figure 13 shows the number of miles of near-stream open land use also correlates well with an increase in the number of somewhat sensitive species ($r = 0.9604, p < 0.0396$). This also supports the conclusion that open near-stream land uses promote water quality.

Figures 14 and 15 show how as the *percent* of commercial land use increases along the stream, water quality is degraded. In Figure 14, the number of somewhat sensitive species increases ($r = 0.9574, p < 0.0426$). Likewise, the number of individuals from tolerant species increases with commercial land uses (Figure 15). The large proportion of impervious (concrete) surfaces and storm drains increases greatly in commercial areas. This is consistent with most studies of urban runoff (Arnold and Gibbons, 1996).

Figures 16 – 18 address the influences of riparian habitat on macroinvertebrate populations. Figure 16 shows that the number of somewhat sensitive species decreases with an increase in the *percent* concrete habitat in the streambed ($r = -0.8050, p < 0.1950$). Although not statistically significant, the relationship is clear. Much of the upper reaches of the Ward Creek watershed are in concrete tunnels. Figure 17 demonstrates that as the *percent* of tunnel increases, the number of somewhat sensitive species decreases, indicating degradation in water quality ($r = -0.9464, p < 0.0537$). On the positive side, Figure 18 indicates that as the *percent* of closed-canopy riparian habitat increases, the number of somewhat sensitive species

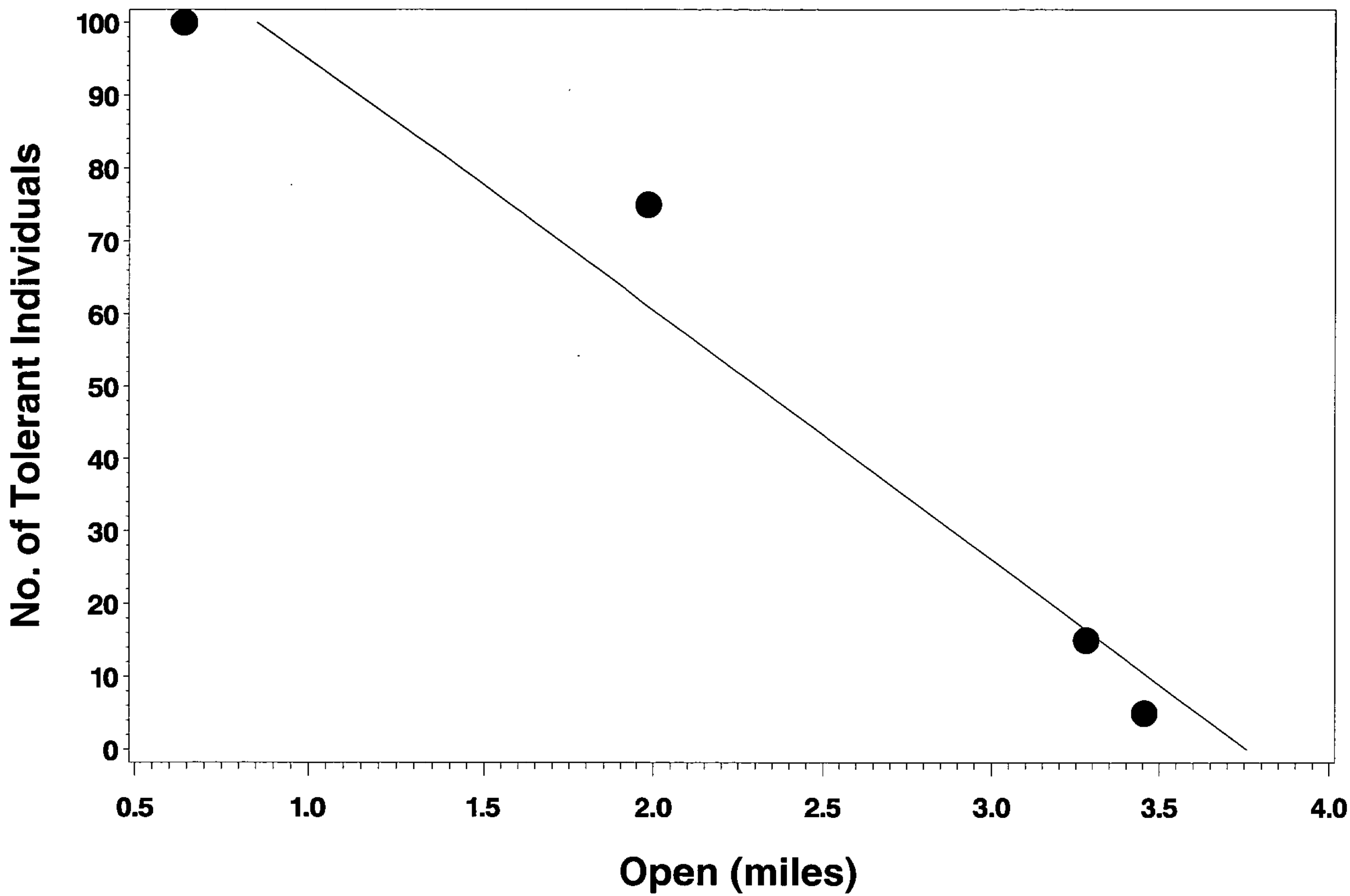


Figure 12. Number of specimens of tolerant species collected as a function of the total stream-miles of open land use.

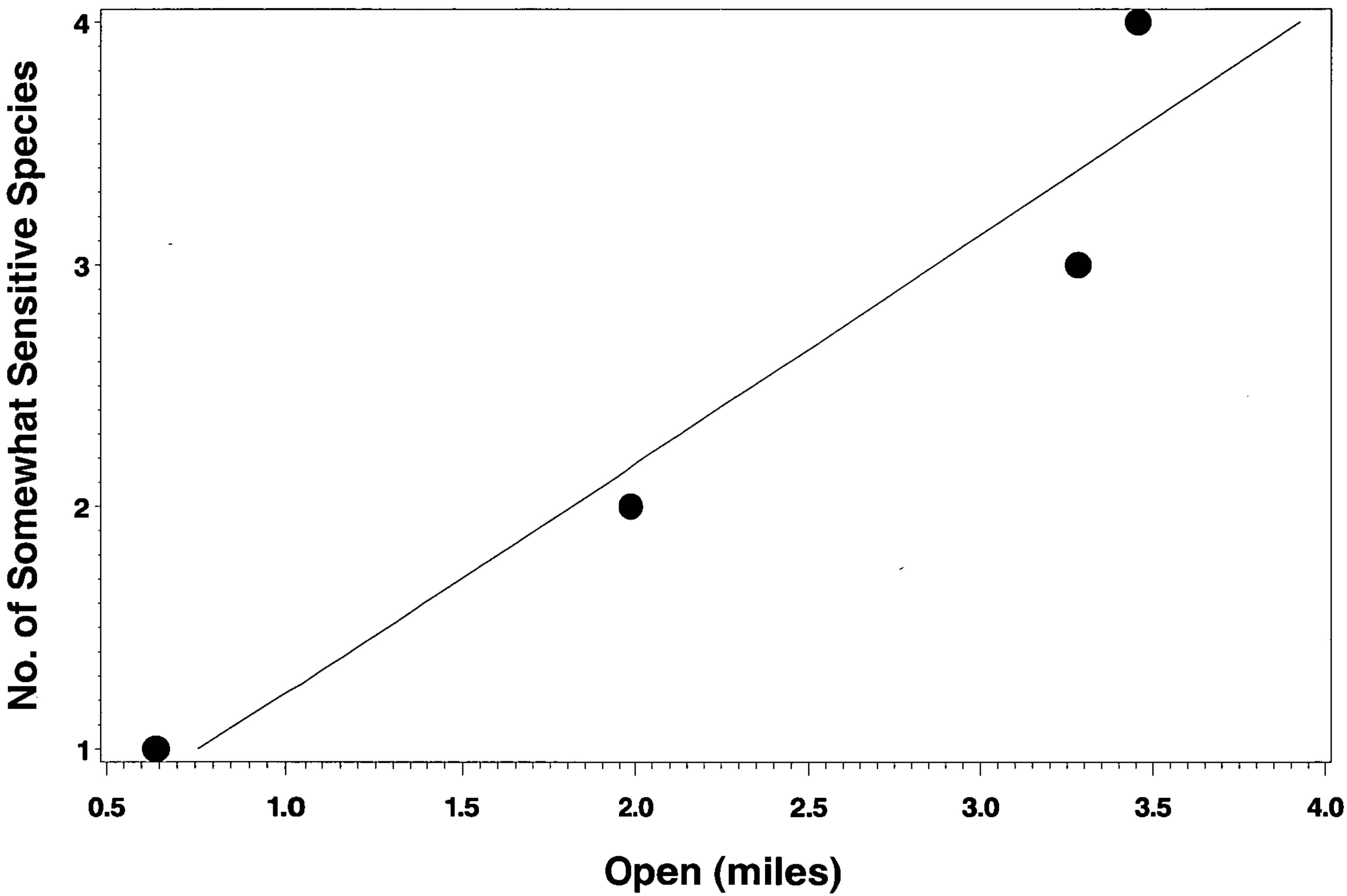


Figure 13. Number of somewhat sensitive species collected as a function of the total stream-miles of open land use.

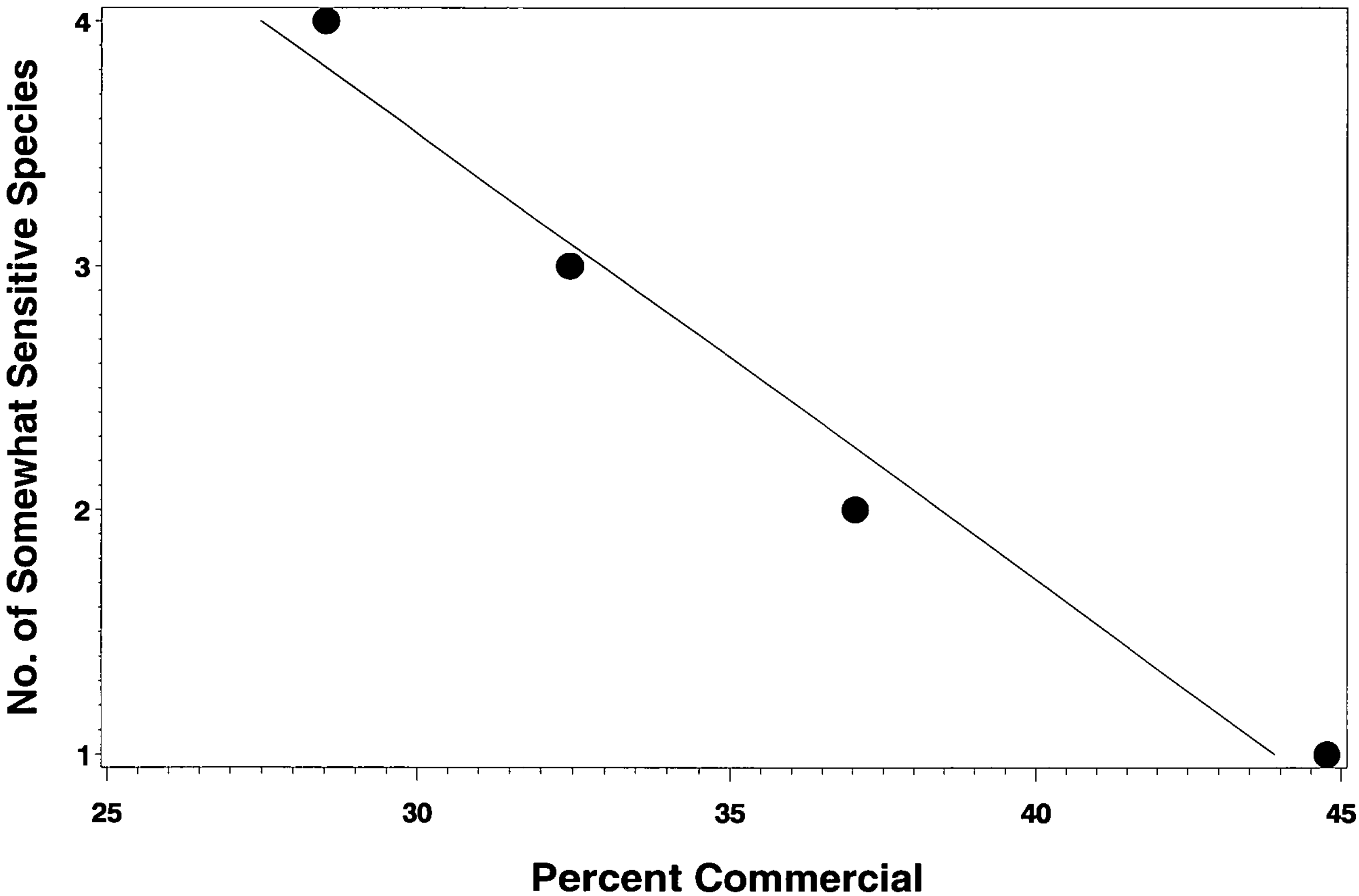


Figure 14. Number of somewhat sensitive species collected as a function of the percent of commercial near-stream land use.

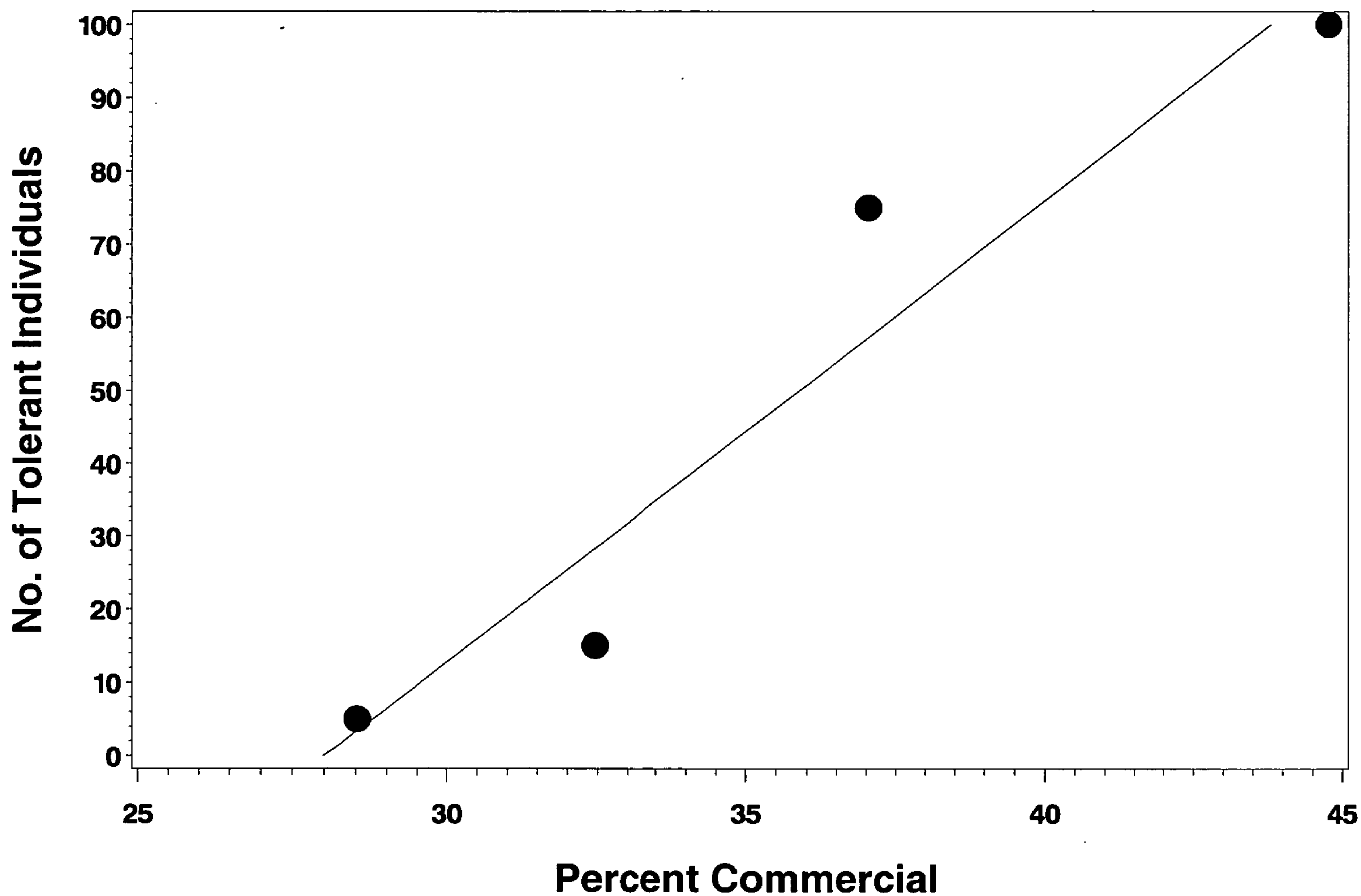


Figure 15. Number of specimens of tolerant species collected as a function of the percent of commercial near-stream land use.

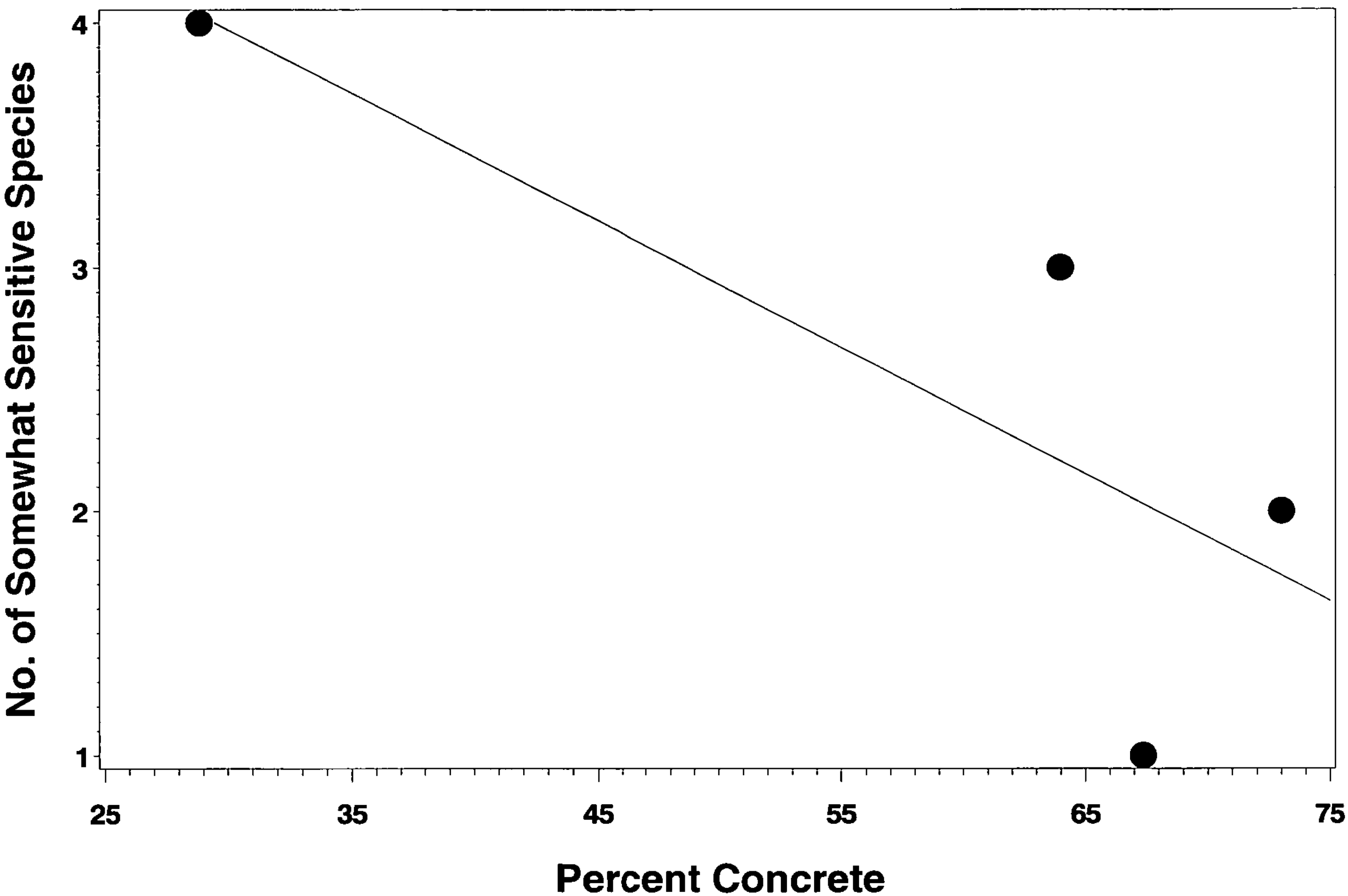


Figure 16. Number of somewhat sensitive species collected as a function of the percent of concrete riparian habitat.

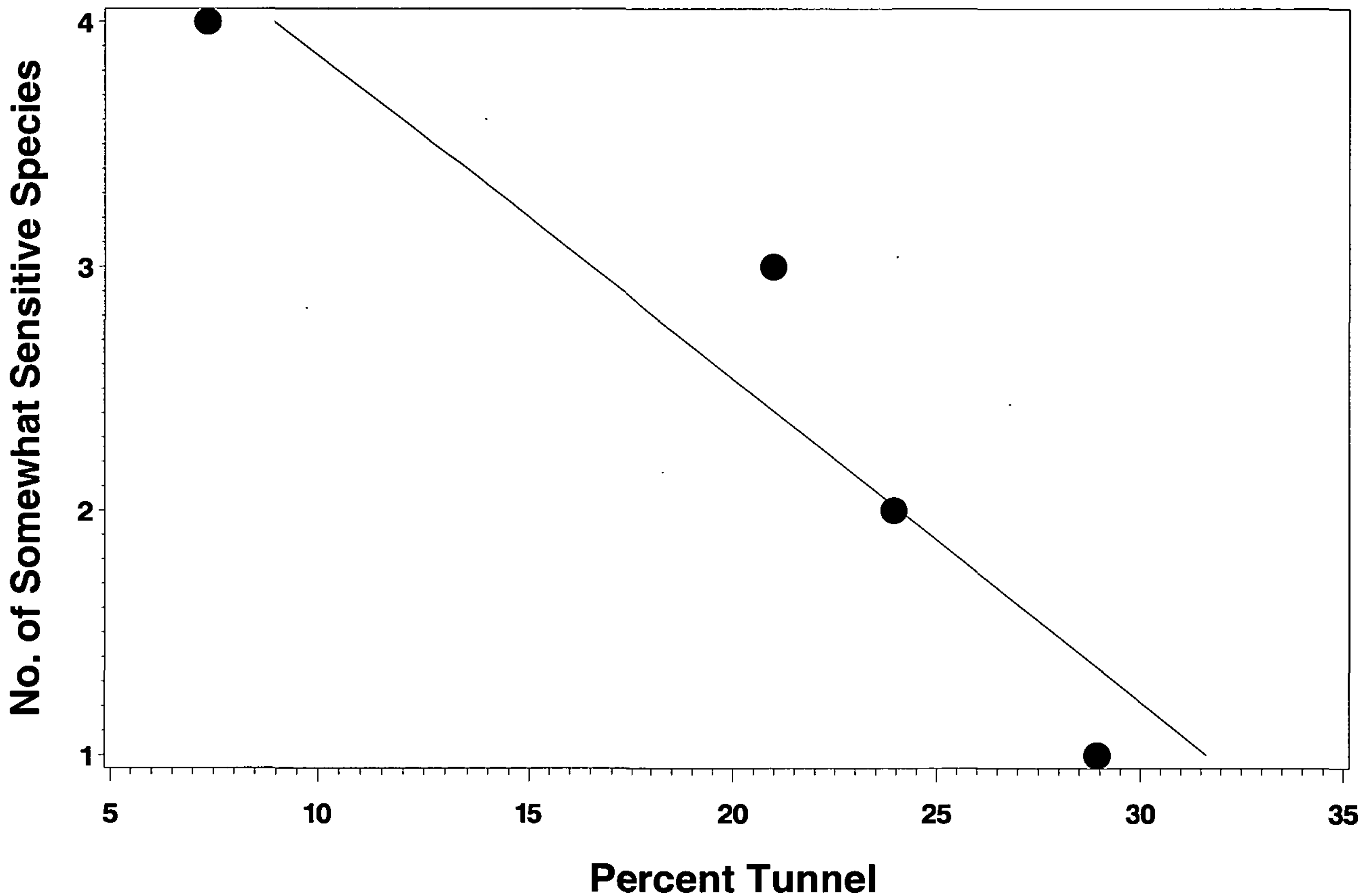


Figure 17. Number of somewhat sensitive species collected as a function of the percent of tunnel riparian habitat.

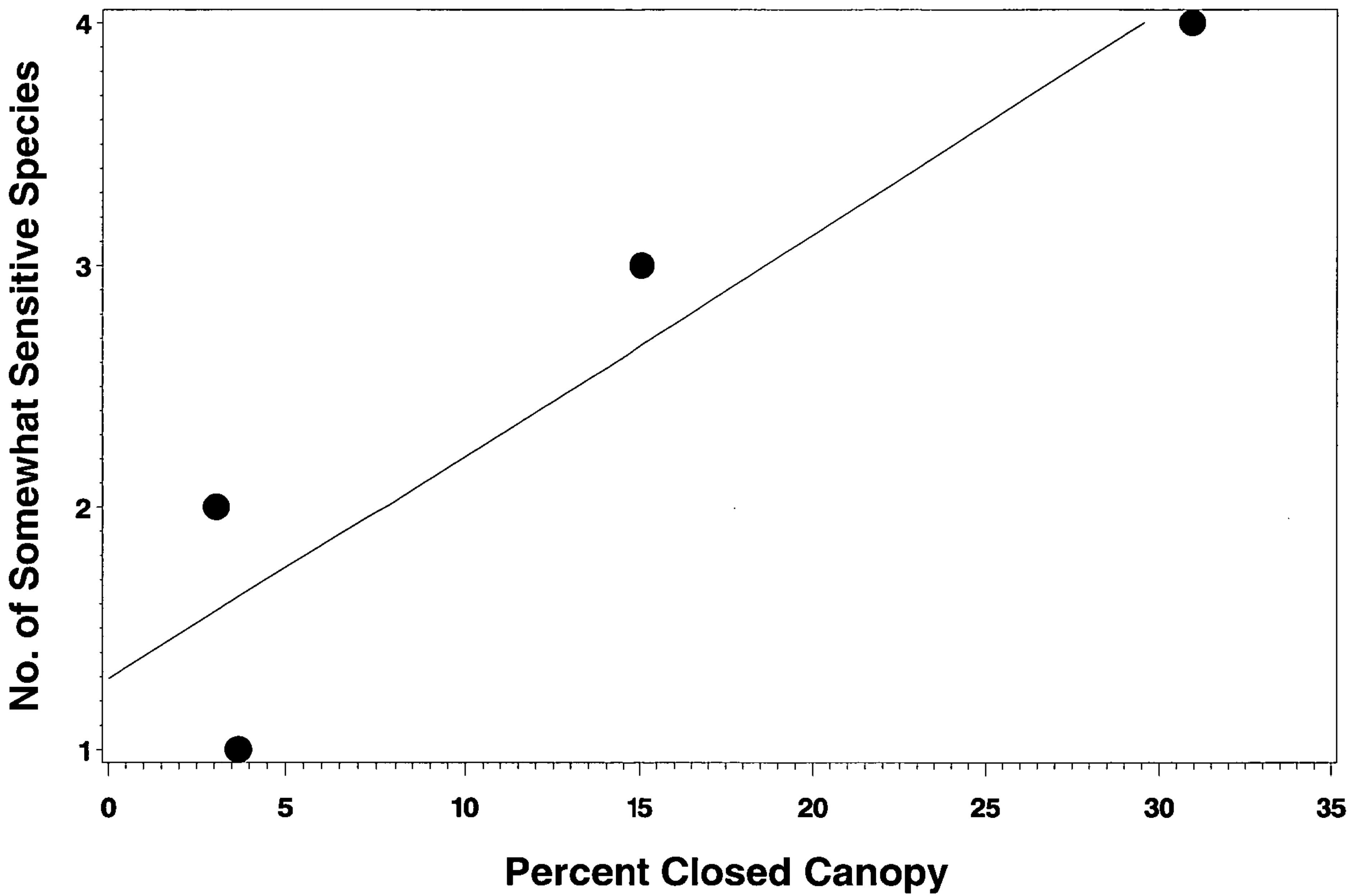


Figure 18. Number of somewhat sensitive species collected as a function of the percent of closed canopy riparian habitat.

increases ($r = 0.9268$, $p < 0.0732$). Again, this increase in water quality is not statistically significant, but does show a clear pattern.

IMPLICATIONS FOR FUTURE WORK

Despite the limited success of this project to produce an automated method to delineate and identify riparian habitats, it does demonstrate how to classify areal features for hydrologic interpretation using aerial photographs and existing vector-based GIS data.

A significant conclusion from this study is the importance of seasonal coverage of imagery used for automated analysis of hydrologic phenomena. The temporal differences in the data used from the merged image shown in Table 4. Figure 3 clearly shows the radiometric and spectral differences that result from these combinations. This is a particularly acute problem for urban areas because they tend to change the character of their landscapes much more frequently than rural areas. The differences in the sampling dates of the SPOT and TM imagery used in this project is two to three years, depending on the panel. In a fast developing area, such as Baton Rouge, many changes will take place. Large tracts of undeveloped land are converted to residential subdivisions, shopping malls, and commercial and manufacturing facilities.

The macroinvertebrate water quality index facet of this study demonstrates its use in a regular reconnaissance program. Although not definitive with regard to establishing baseline data, it did demonstrate its sensitivity to environmental insults.

In the future, care should be taken to address the following concerns:

1. Environmental processes are seasonal in nature. Whenever possible, two to four "seasons" should be sampled and several images produced.

2. Because of the seasonal nature of environmental phenomena, merged data products and products that "tile" several images must match season (or month) and year to minimize natural variation in annual and seasonal cycles.

3. A regular, longitudinal sampling study should be performed to quantify and characterize the spatial and temporal cycles of macroinvertebrate communities in a watershed.

Perhaps the most significant implication of this work is the problems related to the registration of spatial data from different sources. One of the most important features of a GIS is its ability to combine information from different sources (Berry, 1993). Without spatial coincidence of data sources, a great deal of time and resources must be spent reorienting data to line-up with each other. Figures 1 and 2 demonstrate the large differences between various "official" data. Each of these data sources adheres to national map standards (USGS, 1980). These problems are avoided by mapping features from photographs or imagery to existing vector data.

The state of Louisiana has spent a large amount of money on purchasing digital orthophotoquads (DOQQ) of the state. As the digital orthophotoquads come into common use, they will be combined with other spatial data. The pixel size (resolution) of the DOQQs is 1 meter. Therefore, it can distinguish features that are $1/100^{th}$ the size of features distinguishable by a 10 meter, SPOT-TM image. This increase in "accuracy" is a double-edged sword. None of the presently available digital data match the DOQQ images. More importantly, as resolution increases, so do the number of changes expected to be observed in an image. This adds a greater temporal dimension to image uncertainty. Small changes in foliage, landscaping, construction, *etc.* will accumulate across an image with a 1-meter resolution. As an image ages, it will become less "accurate." Images will need to be updated more frequently to maintain their informational integrity.

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APPENDICES

A. Water Quality Sampling Stations

B. Peak Stage/Flow, Partial Record Stations

C. Inventory of Near-stream Land use and Riparian Habitat

D. Macroinvertebrate Diversity Survey

Appendix A – USGS Water Quality Sampling Stations

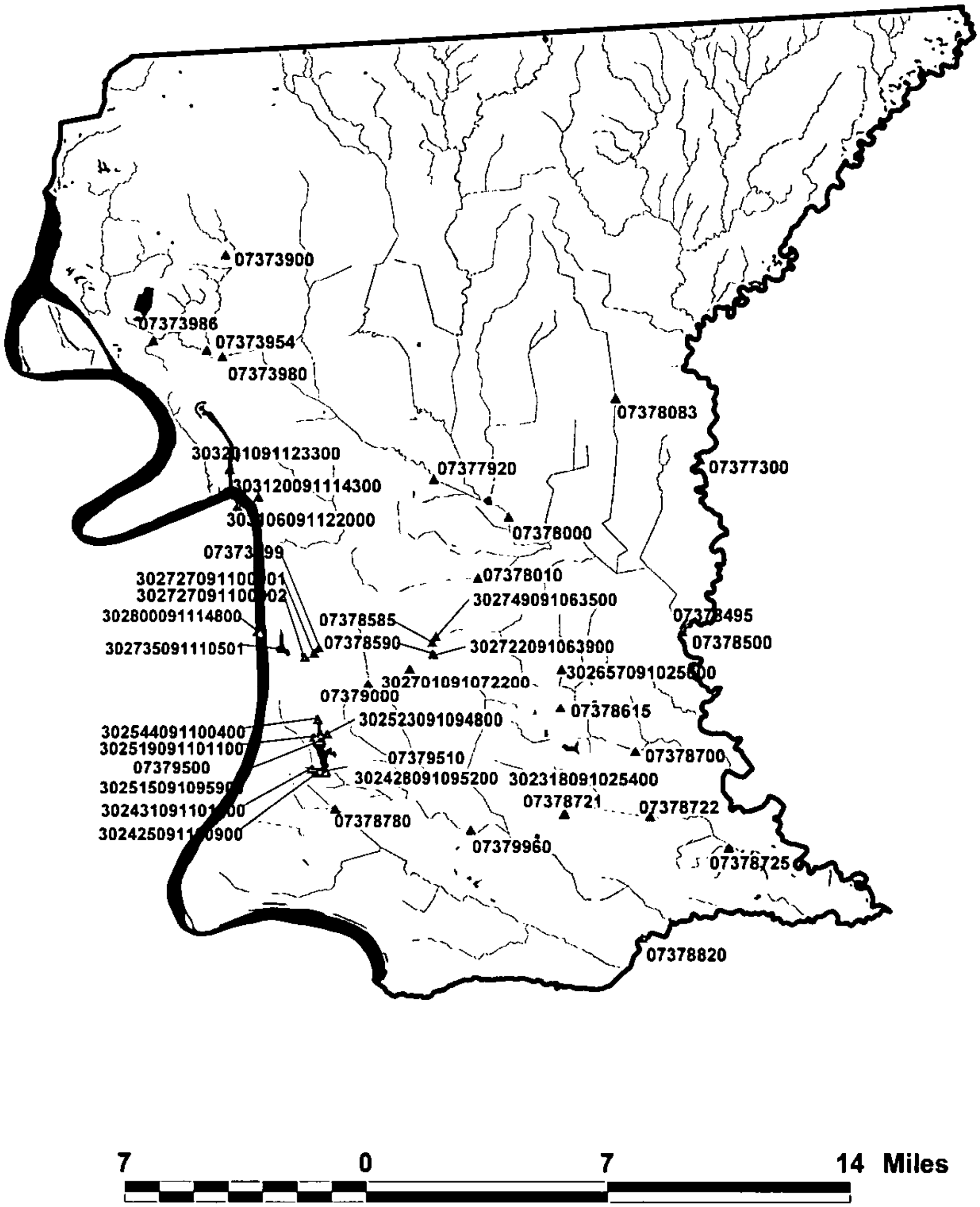

Figure A-1. Locations of USGS water quality sampling stations in East Baton Rouge Parish, as of January , 2000.

Table A-1.
USGS Water Quality Sampling Stations

USGS Station ID	USGS Station Name
07373900	BAYOU BATON ROUGE ABOVE BAKER, LA.
07373954	BAYOU BATON ROUGE ABOVE BAKER CANAL NR BAKER, LA
07373980	BAKER CANAL NEAR BAKER, LA.
07373986	BAYOU BATON ROUGE BELOW BAKER CANAL NR BAKER, LA
07373999	TRIB. TO CAPITOL LAKE @ 21ST ST PUMP STATION
07377300	AMITE RIVER AT MAGNOLIA, LA
07377920	CYPRESS BA AT HOOPER ROAD NR BATON ROUGE LA
07378000	COMITE RIVER NEAR COMITE, LA.
07378010	HURRICANE CK NR BATON ROUGE, LA
07378083	BEAVER BAYOU AT HOOPER RD NR BATON ROUGE, LA
07378495	COMITE RIVER NEAR DENHAM SPRINGS, LA.
07378500	AMITE RIVER NEAR DENHAM SPRINGS, LA.
07378585	TRIB TO JONES CREEK NR TOM DRIVE @ BATON ROUGE, LA
07378590	TRIB. TO JONES CREEK NR LOBDELL BLVD @ BATON ROUGE
07378615	TRIB.TO JONES CREEK NR GOODWOOD BLVD @ BATON ROUGE
07378700	JONES CK NR WOODLAWN SCHOOL NR BATON ROUGE, LA
07378721	TRIB.TO CLAYCUT BAYOU NR INDUSTRIPLEX BLVD NR B.R,
07378722	CLAYCUT BAYOU AT ANTIOCH ROAD
07378725	CLAY CUT BYU NR HOPE VILLA, LA
07378735	BYU PAUL NR BURTVILLE, LA
07378780	BAYOU FOUNTAIN AT BEN HUR RD. BATON ROUGE, LA.
07378820	BYU MANCHAC NR KLEINPETER, LA
07379000	WARD CREEK AT GOVERNMENT STREET, AT BATON ROUGE,
07379500	BYU DUPLANTIER @ CITY PARK LK @ BATON ROUGE, LA
07379510	BYU DUPLANTIER @ STANFORD AV @ BATON ROUGE, LA
07379960	DAWSON CREEK AT BLUEBONNET BOULEVARD
302318091025400	DRAINAGE DITCH (VII) @ SUN BELT COURT
302425091100900	COLLEGE LK @ OUTFLOW @ BATON ROUGE, LA
302428091095200	UNIVERSITY LK @ OUTFLOW @ BATON ROUGE, LA
302431091101600	CAMPUS LK @ OUTFLOW @ BATON ROUGE, LA
302515091095900	CITY PARK LK @ OUTFLOW @ BATON ROUGE, LA
302519091101100	LK CREST @ OUTFLOW @ BATON ROUGE, LA
302523091094800	LK ERIE @ OUTFLOW @ BATON ROUGE, LA
302544091100400	CITY PARK LK IN NW CORNER @ BATON ROUGE, LA
302657091025600	DRAINAGE CANAL GOODWOOD BLVD .5 MI E SHERWOOD FORS
302701091072200	BATON ROUGE RAINWATER @ LA.DISTRICT OFFICE
302722091063900	DRAINAGE CANAL @ LOBDELL BLVD & BON MARCHE MALL
302727091100901	DRAINAGE CANAL CAPITOL LAKE @ BR DOWNSTR PUMP STN
302727091100902	DRAINAGE CANAL CAPITOL LAKE @ BR NR GRACE ST.

Table A-1.
USGS Water Quality Sampling Stations

USGS Station ID	USGS Station Name
302735091110501	CAPITOL LAKE @ I-110
302749091063500	DRAINAGE CANAL AT TOM DR .1 MI E WOODDALE BLVD
302800091114800	MISSISSIPPI RIVER AT MILE 231
303106091122000	MISSISSIPPI R @ WILKINSON POINT NR BATON ROUGE
303120091114300	LAKE KERNAN (STN. 1) MID-LAKE
303201091123300	MISSISSIPPI R @ BATON ROUGE HARBOR @ BATON ROUGE

**Table A-2.
USGS Water Quality Parameters
Sampled in Baton Rouge**

Parameter Designation	Description
00010	WATER TEMPERATUR (DEGREES)
00027	COLLECTING AGENC (CODE NUMBER)
00028	ANALYZING AGENCY (CODE NUMBER)
00070	TURBIDITY (JCU)
00075	TURBIDITY (MG/L) (MG/L AS SIO2)
00080	COLOR PLATINUM-COBALT
00095	SPECIFIC CONDUCT US/CM @ 25C
00340	COD HIGH LEVEL M (MG/L)
00400	PH, WH, FIELD (STANDARD UNITS)
00403	PH, WH, LABORATO (STANDARD UNITS)
00405	CARBON DIOXIDE D (MG/L AS CO2)
00410	ANC, FET, FIELD (MG/L AS CACO3)
00440	ANC HCO3 FET FIE (MG/L AS HCO3)
00445	ANC CARB FET FIE (MG/L AS CO3)
00556	OIL AND GREASE R (MG/L)
00557	OIL AND GREASE B (MG/KG)
00608	NITROGEN AMMONIA (MG/L AS N)
00610	NITROGEN AMMONIA (MG/L AS N)
00613	NITROGEN, NITRITE MG/L AS N
00615	NITROGEN, NITRITE MG/L AS N
00618	NITROGEN NITRATE (MG/L AS N)
00623	NITRO AMN & ORG (MG/L AS N)
00630	NO2 + NO3 TOTAL (MG/L AS N)
00631	NO2 + NO3 DISSOL (MG/L AS N)
00665	PHOSPHORUS TOTAL (MG/L AS P)
00666	PHOSPHORUS DISS. (MG/L AS P)
00671	PHOSPHORUS ORTHO (MG/L AS P)
00677	PHOSPHORUS HYDRO (MG/L AS P)
00720	CYANIDE TOTAL (MG/L AS CN)
00900	HARDNESS TOTAL (MG/L AS CAO3)
00902	NONCARBONATE HAR (MG/L AS CACO3)
00915	CALCIUM DISSOLVE (MG/L AS CA)
00925	MAGNESIUM DISSOL (MG/L AS MG)
00930	SODIUM DISSOLVED (MG/L AS NA)
00931	SODIUM ADSORPTIO (RATIO)
00932	SODIUM, PERCENT PERCENT
00935	POTASSIUM DISSOL (MG/L AS K)

**Table A-2.
USGS Water Quality Parameters
Sampled in Baton Rouge**

Parameter Designation	Description
00940	CHLORIDE DISSOLV (MG/L AS CL)
00945	SULFATE DISSOLVE (MG/L AS SO4)
00950	FLUORIDE DISSOLV (MG/L AS F)
00955	SILICA DISSOLVED (MG/L AS SIO2)
01000	ARSENIC DISSOLVE (UG/L AS AS)
01002	ARSENIC TOTAL (UG/L AS AS)
01010	BERYLLIUM DISSOL (UG/L AS BE)
01012	BERYLLIUM TOTAL (UG/L AS BE)
01020	BORON DISSOLVED (UG/L AS B)
01025	CADMIUM DISSOLVE (UG/L AS CD)
01027	CADMIUM TOTAL (UG/L AS CD)
01030	CHROMIUM DISSOLV (UG/L AS CR)
01032	CHROMIUM HEXAVAL (UG/L AS CR)
01034	CHROMIUM TOTAL (UG/L AS CR)
01035	COBALT DISSOLVED (UG/L AS CO)
01040	COPPER DISSOLVED (UG/L AS CU)
01042	COPPER TOTAL (UG/L AS CU)
01045	IRON TOTAL (UG/L AS FE)
01046	IRON DISSOLVED (UG/L AS FE)
01049	LEAD DISSOLVED (UG/L AS PB)
01051	LEAD TOTAL (UG/L AS PB)
01052	LEAD TOTAL BOT. (UG/G AS PB)
01056	MANGANESE DISSOL (UG/L AS MN)
01059	THALLIUM TOTAL (UG/L AS TL)
01065	NICKEL DISSOLVED (UG/L AS NI)
01067	NICKEL TOTAL (UG/L AS NI)
01075	SILVER DISSOLVED (UG/L AS AG)
01077	SILVER TOTAL (UG/L AS AG)
01090	ZINC DISSOLVED (UG/L AS ZN)
01092	ZINC TOTAL (UG/L AS ZN)
01095	ANTIMONY DISSOLV (UG/L AS SB)
01106	ALUMINUM DISSOLV (UG/L AS AL)
01145	SELENIUM DISSOLV (UG/L AS SE)
01147	SELENIUM TOTAL (UG/L AS SE)
04024	PROPACHLOR DISS (UG/L)
04028	BUTYLATE DISS RE (UG/L)
04029	BROMACIL DISS RE (UG/L)
04037	PROMETON DISS RE (UG/L)

**Table A-2.
USGS Water Quality Parameters
Sampled in Baton Rouge**

Parameter Designation	Description
04040	DEETHYL ATRAZINE (UG/L)
04041	CYANAZINE DISS R (UG/L)
04064	THALLIUM BM DS < (UG/G)
04095	FONOFOX DISS REC (UG/L)
22703	URANIUM,NATURAL, UG/L AS U
30217	DIBROMOMETHANE,W UG/L
31501	COLIFORM, TOTAL COLS./100 ML
31625	COLIFORM FECAL 0 COLS./100 ML
31633	E.COLI,UREASE,MF COL/100 ML
31673	FECAL STRPT KF A COLS./100 ML
32101	BROMODICHLOROMET UG/L
32102	CARBON TETRACHLO UG/L
32103	1,2-DICHLOROETHA UG/L
32104	BROMOFORM TOTAL UG/L
32105	CHLORODIBROMOMET UG/L
32106	CHLOROFORM TOTAL UG/L
32730	PHENOLS, TOTAL UG/L
34010	TOLUENE, TOTAL UG/L
34030	BENZENE, TOTAL UG/L
34200	ACENAPHTHYLENE T (UG/L)
34205	ACENAPHTHENE TOT (UG/L)
34210	ACROLEIN TOT. (UG/L)
34215	ACRYLONITRILE TO (UG/L)
34220	ANTHRACENE TOT. (UG/L)
34230	FLUORANTHENE,BZ. UG/L
34242	FLUORANTHENE BZ. (UG/L)
34247	PYRENE BZ.A.T. (UG/L)
34253	ALPHA BHC UG/L
34259	HEXACHLORIDE,D.B (UG/L)
34273	B2CHLOROETHYL ET (UG/L)
34278	CHLOROETHOXY M. (UG/L)
34283	BIS(2-CHLOROISO. (UG/L)
34292	PHTHALATE,N-BU.B (UG/L)
34301	CHLOROBENZENE (UG/L)
34311	CHLOROETHANE UG/L
34320	CHRYSENE TOTAL U (UG/L)
34336	PHTHALATE,DIETHY (UG/L)
34341	PHTHALATE,DIMETH (UG/L)

Table A-2.
USGS Water Quality Parameters
Sampled in Baton Rouge

Parameter Designation	Description
34351	ENDOSULFAN SULFA (UG/L)
34356	ENDOSULFAN II UN (UG/L)
34361	ENDOSULFAN I WH (UG/L)
34366	ENDRIN ALDEHYDE (UG/L)
34371	ETHYLBENZENE TOT (UG/L)
34376	FLUORANTHENE TOT (UG/L)
34381	FLUORENE TOTAL U (UG/L)
34386	CYCLOPENTADIENE (UG/L)
34396	ETHANE, HEXACHLO (UG/L)
34403	PYRENE,INDENO TO (UG/L)
34408	ISOPHORONE TOTAL (UG/L)
34413	METHYLBROMIDE TO (UG/L)
34418	METHYLCHLORIDE,T (UG/L)
34423	METHYLENE CHLORI (UG/L)
34428	N-NI.N-PROPYLAMI (UG/L)
34433	N-NI.DIPHENYLAMI (UG/L)
34438	N-NI.DIMETHYLAMI (UG/L)
34447	BENZENE, NITRO- (UG/L)
34452	PARACH.META CRES (UG/L)
34461	PHENANTHRENE TOT (UG/L)
34469	PYRENE TOTAL (UG (UG/L)
34475	TETRACHLOROETHYL (UG/L)
34488	TRICH.FLUOR.METH (UG/L)
34496	DICHLOROETHANE 1 (UG/L)
34501	DICHLOROETHYLENE (UG/L)
34506	TRICHLOROETHANE (UG/L)
34511	TRICHLOROETHANE (UG/L)
34516	1122TETRACHLORO (UG/L)
34521	BENZO[GHI]PERYLE (UG/L)
34526	BENZO(A)ANTHRACE (UG/L)
34536	O-DICHLORO-BENZE (UG/L)
34541	DICHLOROPROPANE (UG/L)
34546	TRANSDICH.ETHENE (UG/L)
34551	124TRICHLOROBENZ (UG/L)
34556	DIBENZANTHRACENE (UG/L)
34566	13DICHLORO-BENZE (UG/L)
34571	14DICHLORO-BENZE (UG/L)
34576	CHL.ETH.VIN.ETHE (UG/L)

Table A-2.
USGS Water Quality Parameters Sampled in Baton Rouge

Parameter Designation	Description
34581	CHLORONAPHTHALEN (UG/L)
34586	CHLOROPHENOL TOT (UG/L)
34591	NITROPHENOL2 TOT (UG/L)
34596	PHTHALATE,DINOCT (UG/L)
34601	DICHLOROPHENOL2, (UG/L)
34606	DIMETHYLPHENOL2, (UG/L)
34611	DINITROTOLUENE2, (UG/L)
34616	DINITROPHENOL2,4 (UG/L)
34621	TRICHLOROPHENOL (UG/L)
34626	DINITROTOLUENE2, (UG/L)
34631	DICHLOROBENZIDIN (UG/L)
34636	4 BR.PH.PHENYLET (UG/L)
34641	4 CH.PH.PHENYLET (UG/L)
34646	4-NITROPHENOL TO (UG/L)
34653	P,P' DDE DISSOLV (UG/L)
34657	4,6 DINITRO.OR.C (UG/L)
34668	DICHL.DIFL.METHA (UG/L)
34671	AROCLOR 1016 PCB (UG/L)
34694	PHENOL (6H-50H) (UG/L)
34696	NAPHTHALENE TOTA (UG/L)
34699	TR1,3-DICHL.PROP UG/L
34704	CIS1,3-DICHL.PRO UG/L
34816	BISMUTH BM<180WS UG/G
34870	GOLD BM<63 WSF UG/G

Appendix B – USGS Peak Stage/Flow, Partial Record Stations

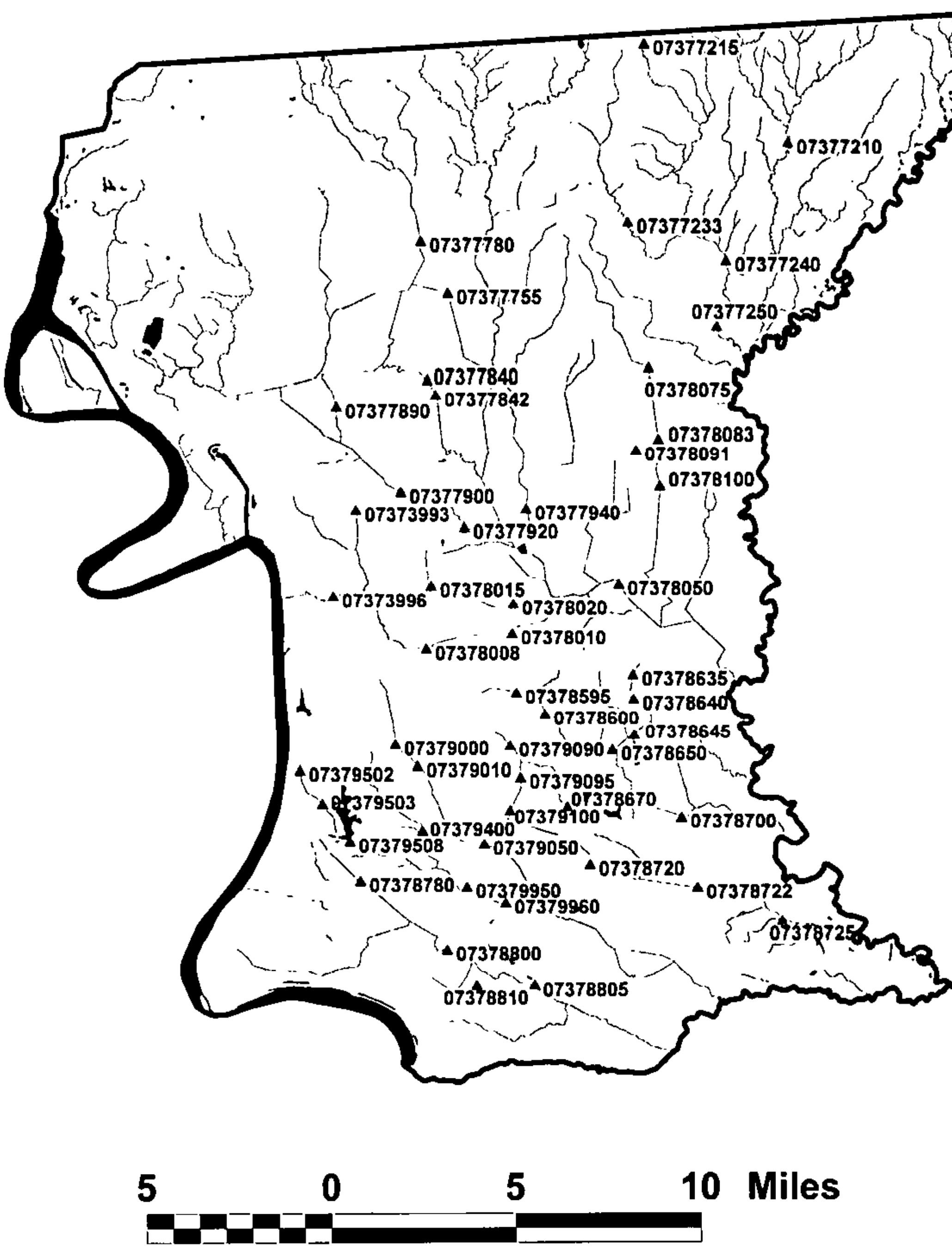

Figure B-1. Locations of USGS partial record (peak stage/flow) stations in East Baton Rouge Parish, as of January , 2000.

Table B-1.
USGS Partial Record Stations

USGS Station ID	Station Name
07373996	MONTE SANO BAYOU AT BATON ROUGE, LA.
07377210	SANDY CREEK NR PRIDE, LA.
07377215	LITTLE SANDY CR. NR MILLDALE, LA.
07377233	BEAVER CREEK AT PEAIRS RD SE OF MILLDALE, LA
07377240	LITTLE SANDY CR. NR. GREENWELL SPRINGS, LA.
07377920	CYPRESS BA AT HOOPER ROAD NR BATON ROUGE LA
07377940	BLACKWATER BYU NR BATON ROUGE, LA
07378100	BEAVER BY AT WAX RD., NR BATON ROUGE, LA.
07378650	JONES CREEK AT OLD HAMMOND HWY NR B. R. LA.
07378700	JONES CK NR WOODLAWN SCHOOL NR BATON ROUGE, LA
07378722	CLAYCUT BAYOU AT ANTIOCH ROAD
07378800	BAYOU FOUNTAIN AT GARDERE LANE NR. B. R. LA.
07378810	BAYOU FOUNTAIN AT BLUEBONNET BOULEVARD,
07379050	WARD CREEK @ ESSEN LANE, NEAR BATON ROUGE, LA.
07379090	N BRANCH WARD CREEK @ GOODWOOD BLVD. @ B. R. LA.
07379095	NORTH BRANCH WARD CREEK AT OLD HAMMOND HWY.
07379100	NORTH BRANCH WARD CREEK @ BATON ROUGE, LA.
07379960	DAWSON CREEK AT BLUEBONNET BOULEVARD
07373993	MONTE SANO AT RYAN AIRPORT, AT BATON ROUGE, LA.
07377250	SANDY CK NR GREENWELL SPRINGS, LA
07377755	WHITE BAYOU E.DIV. CANAL NR BATON ROUGE, LA.
07377780	WHITE BAYOU AT STATE HWY 64 NEAR ZACHARY, LA.
07377840	WHITE BAYOU NEAR BATON ROUGE, LA.
07377842	WHITE BAYOU NEAR BAKER, LA.
07377890	CYPRESS BAYOU AT BAKER, LA.
07377900	CYPRESS BAYOU AT PLANK RD NEAR BATON ROUGE, LA.
07378008	HURRICANE CREEK AT BATON ROUGE, LA.
07378010	HURRICANE CK NR BATON ROUGE, LA
07378015	ROBERTS CANAL AT BATON ROUGE, LA.
07378020	ROBERTS CANAL NEAR BATON ROUGE, LA.
07378050	COMITE RIVER AT GR SP RD NR BATON ROUGE,LA.
07378075	BEAVER BY AT DENHAM RD. NR BATON ROUGE, LA.
07378083	BEAVER BAYOU AT HOOPER RD NR BATON ROUGE, LA
07378091	BEAVER BAYOU TRIB. @ HOOPER RD NR B.R., LA
07378595	JONES CR. AT AIRLINE HWY. AT BATON ROUGE, LA.
07378600	JONES CREEK AT FLORIDA BLVD. AT BATON ROUGE, LA.
07378635	LIVELY BAYOU NORTHEAST OF BATON ROUGE, LA.
07378640	LIVELY BAYOU EAST OF BATON ROUGE, LA.

Table B-1.
USGS Partial Record Stations

USGS Station ID	Station Name
07378645	LIVELY BAYOU SOUTHEAST OF BATON ROUGE, LA.
07378670	WEINER CREEK NR BATON ROUGE, LA.
07378720	CLAY CUT BAYOU AT SIEGEN LANE NR. B. R. LA.
07378725	CLAY CUT BYU NR HOPE VILLA, LA
07378780	BAYOU FOUNTAIN AT BEN HUR RD. BATON ROUGE, LA.
07378805	BAYOU FOUNTAIN TRIB. NEAR BATON ROUGE, LA.
07379000	WARD CREEK AT GOVERNMENT STREET, AT BATON ROUGE,
07379010	WARD CK @ COLLEGE DR @ BATON ROUGE, LA
07379400	DAWSON CREEK @ PERKINS ROAD @ BATON ROUGE, LA.
07379502	CORPORATION CANAL @ OKLAHOMA ST. @ B. R. LA.
07379503	CORPORATION C.AT E.ROOSEVELT ST. AT B. R. LA.
07379508	CORPORATION C.AT STANFORD AVE.AT B. R. LA.
07379950	DAWSON CK. @ STARING LANE NR. BATON ROUGE, LA.

Appendix C – Inventory of Near-stream Land use and Riparian Habitat

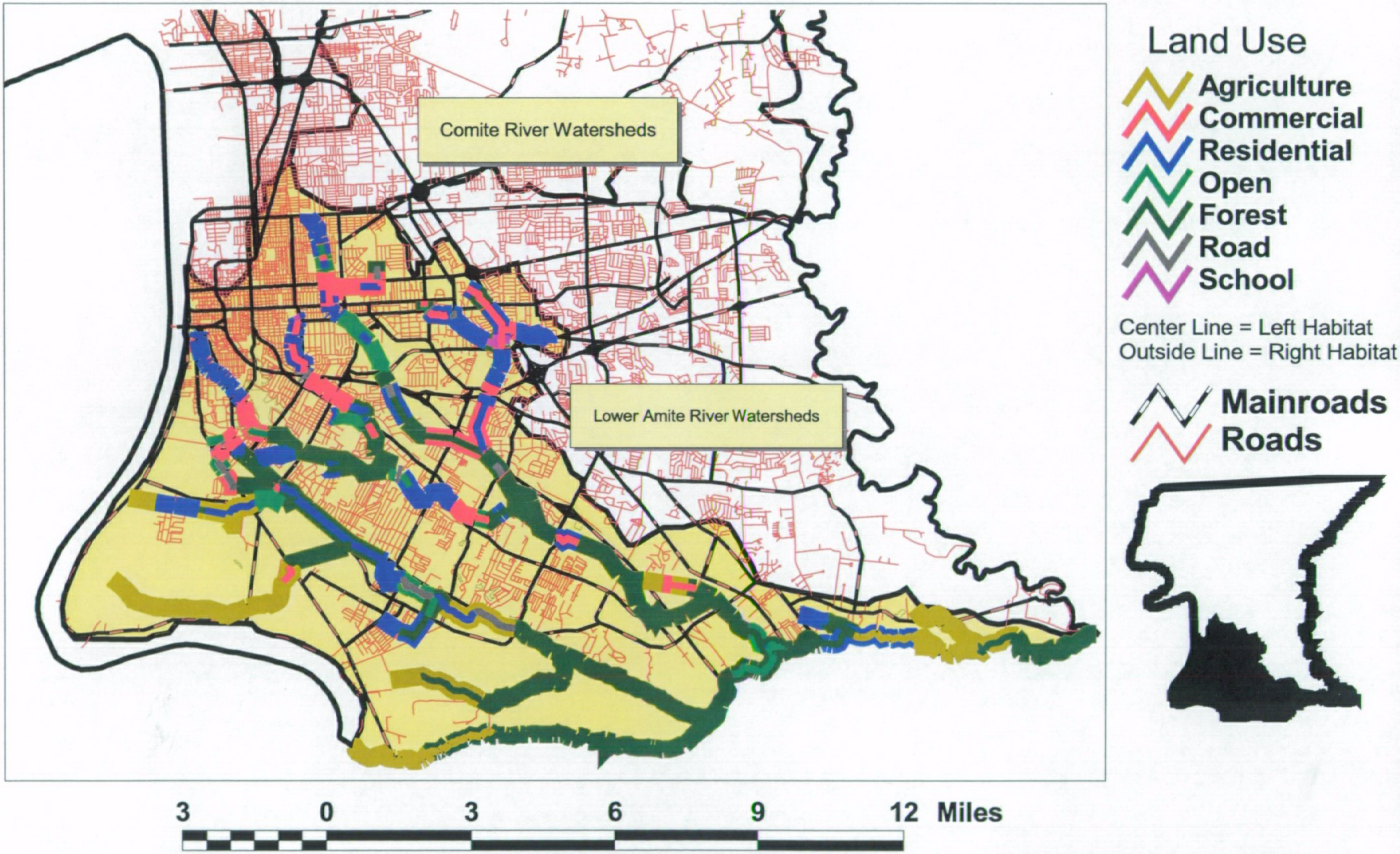

Figure C-1 Near-stream land use in the Bayou Manchac Basin

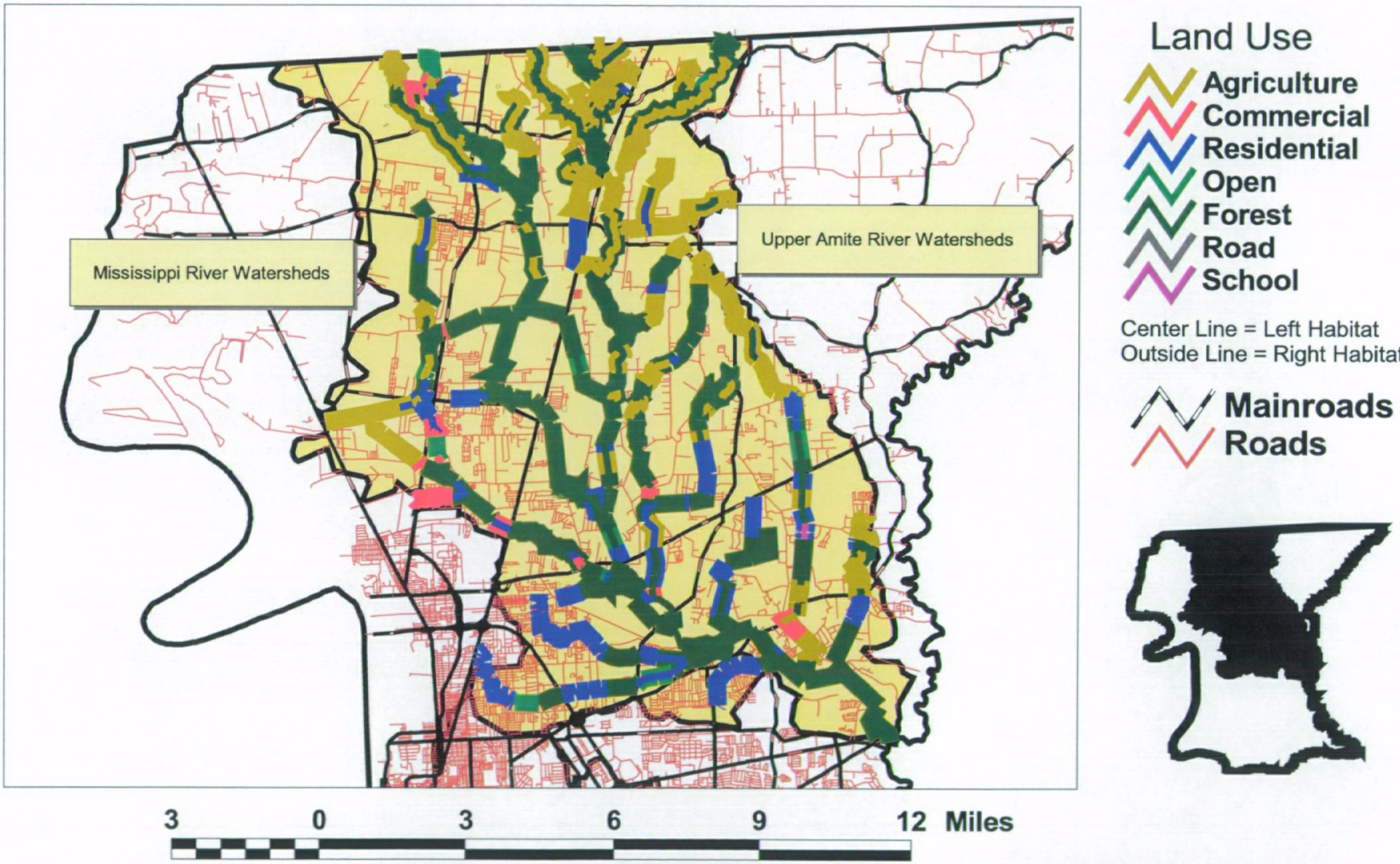

Figure C-2 Near-stream land use in the Comite River Basin

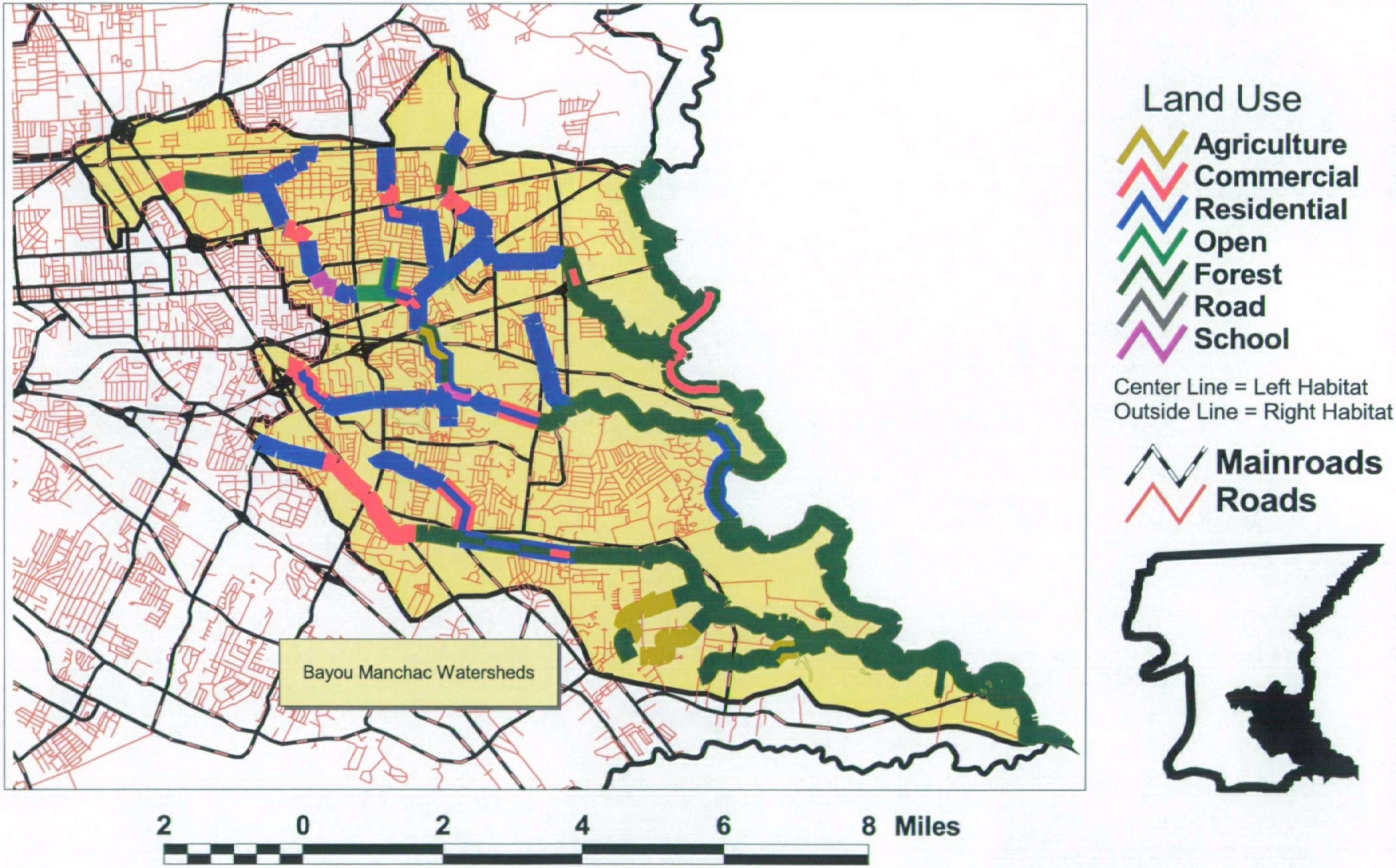

Figure C-3   Near-stream land use in the Lower Amite River Basin

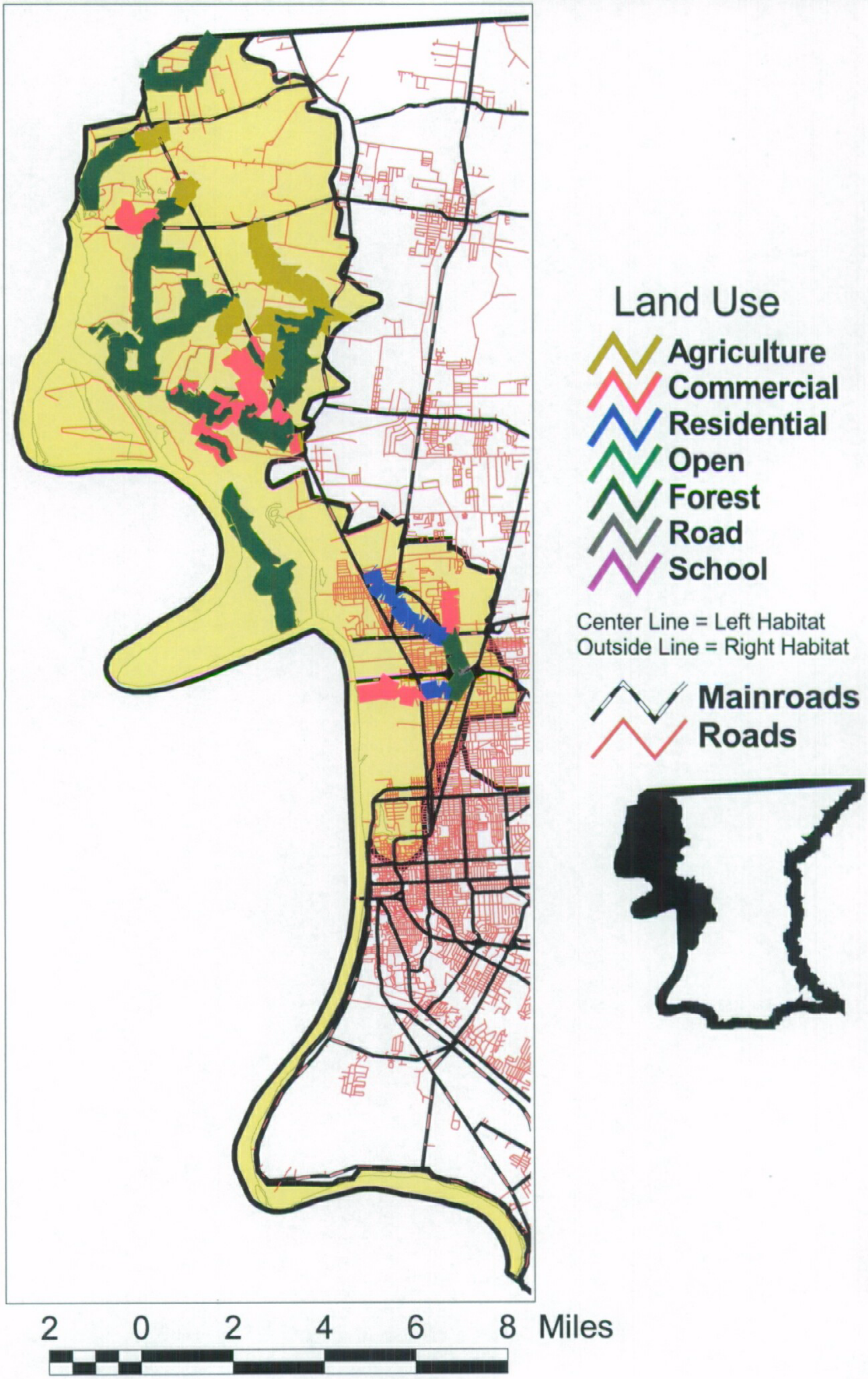

Figure C-4 Near-stream land use in the Mississippi River Basin

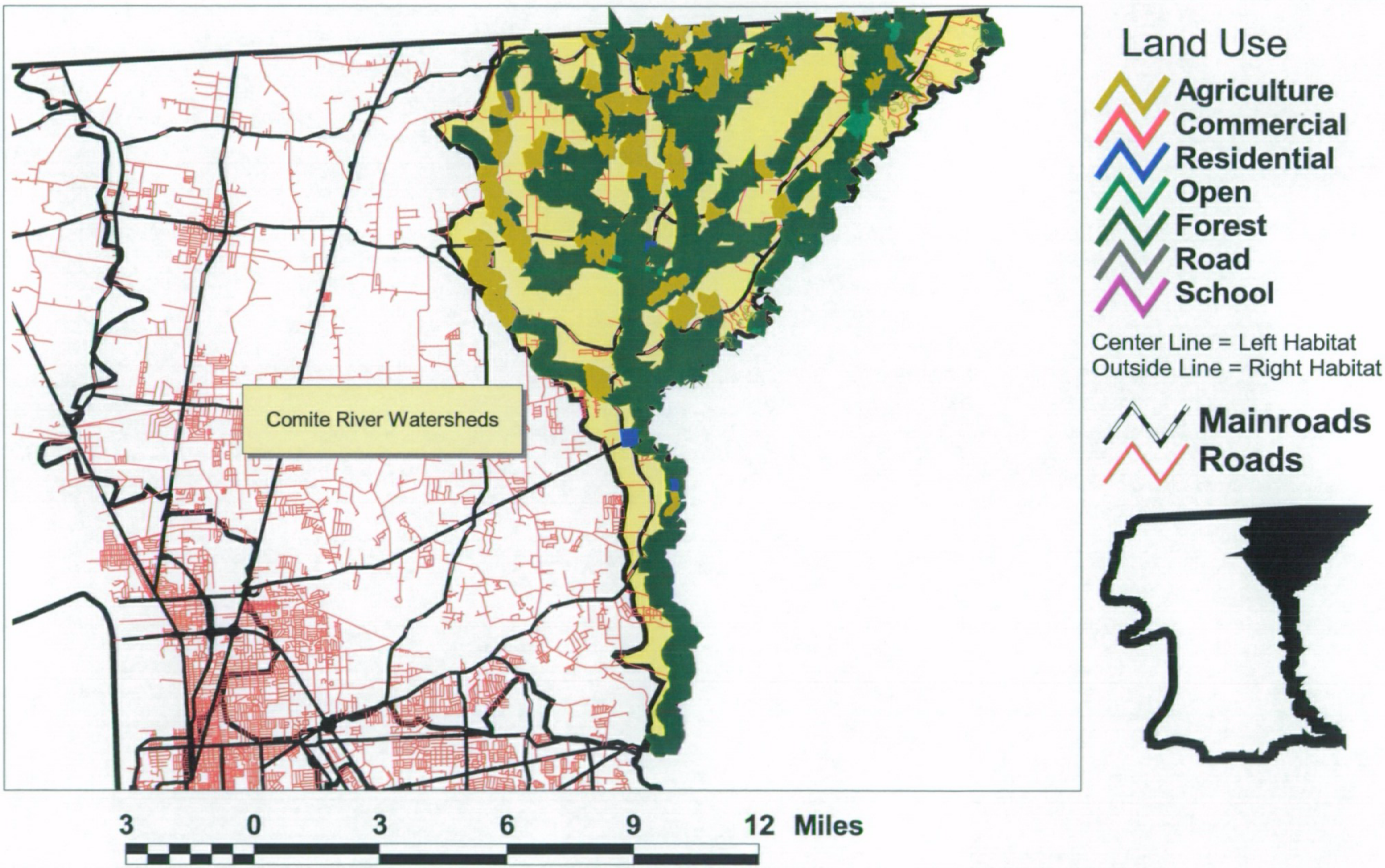

Figure C-5 Near-stream land use in the Upper Amite River Basin

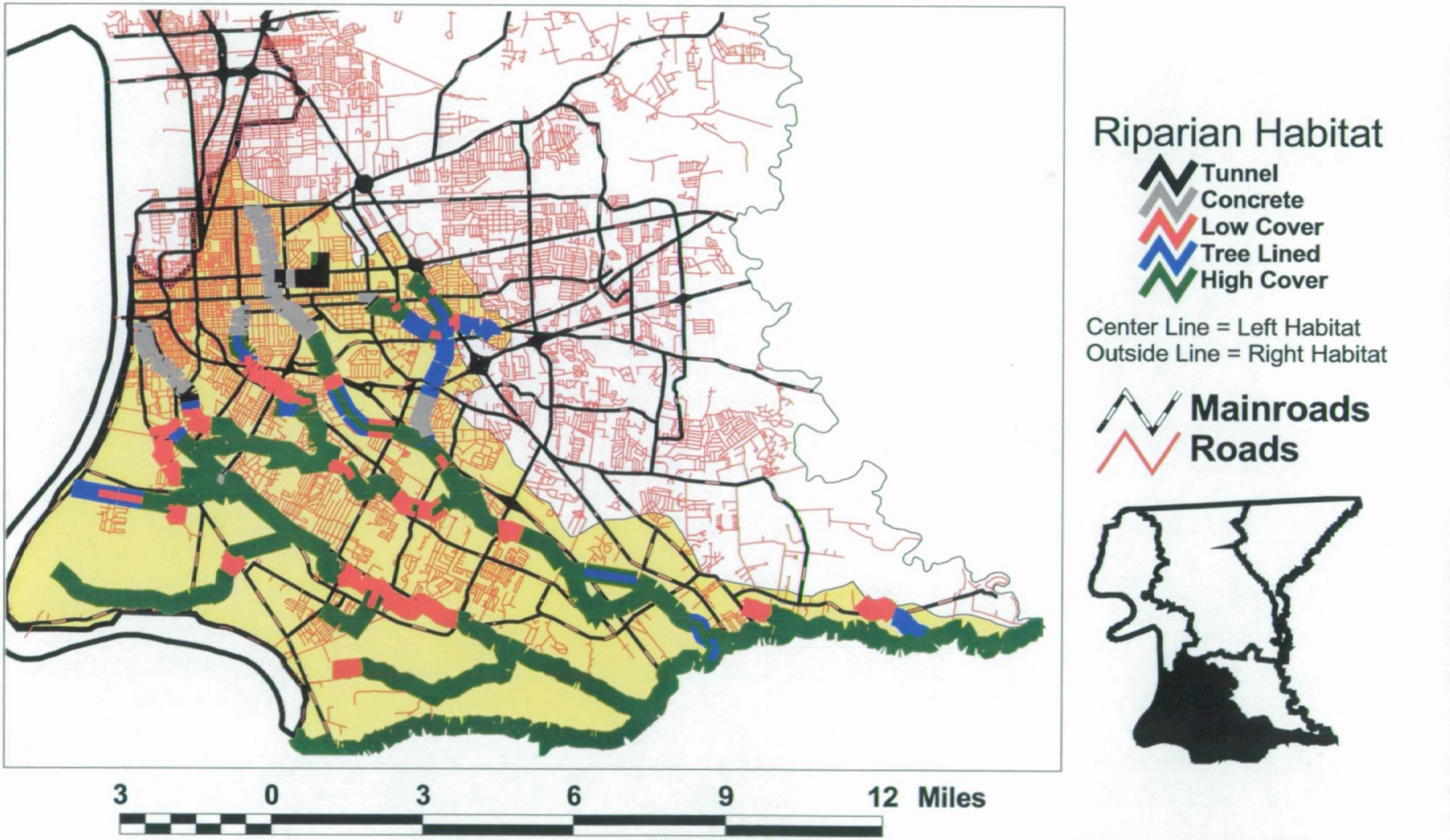

Figure C-6 Riparian habitat in the Bayou Manchac Basin

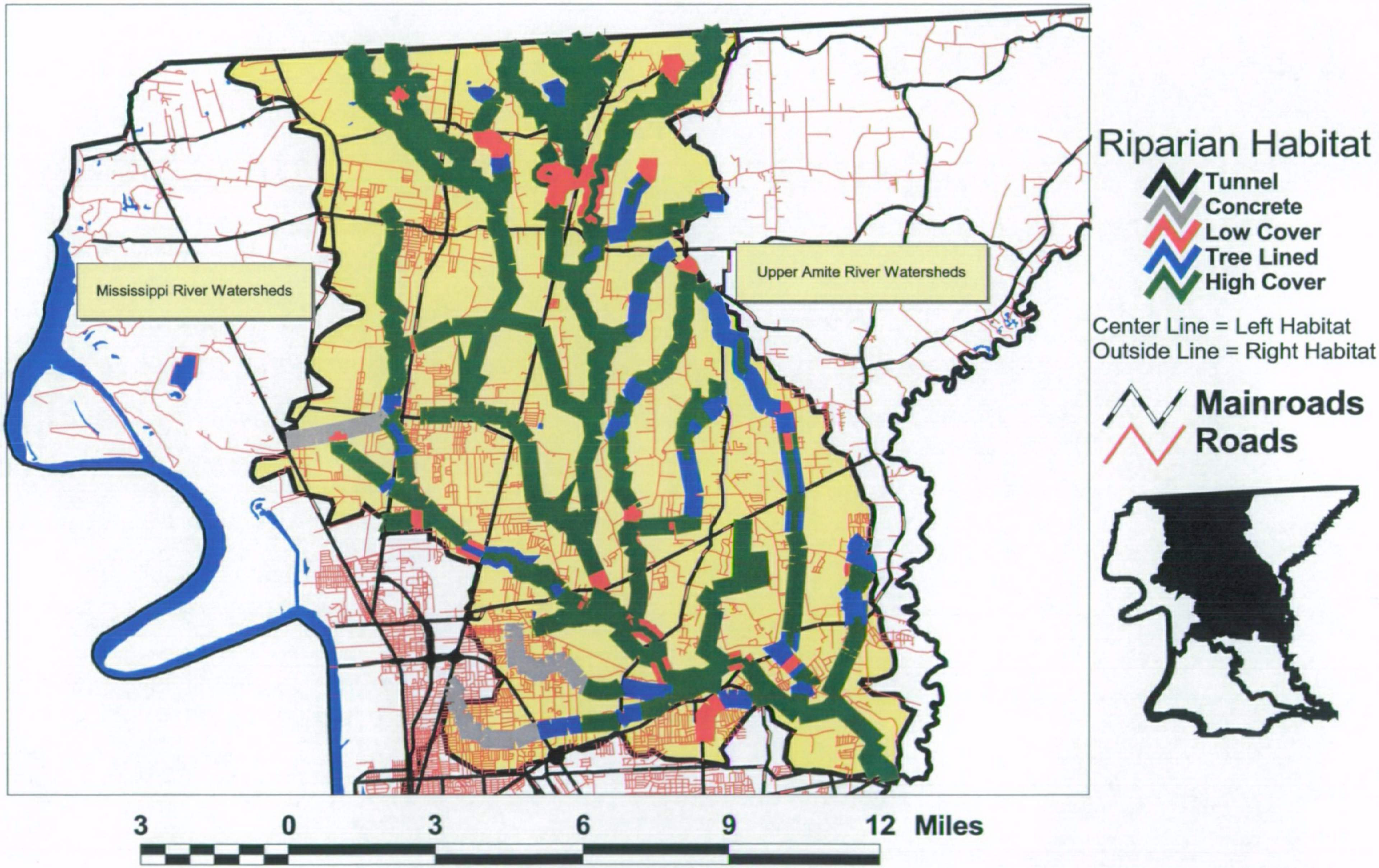

Figure C-7 Riparian habitat in the Comite River Basin

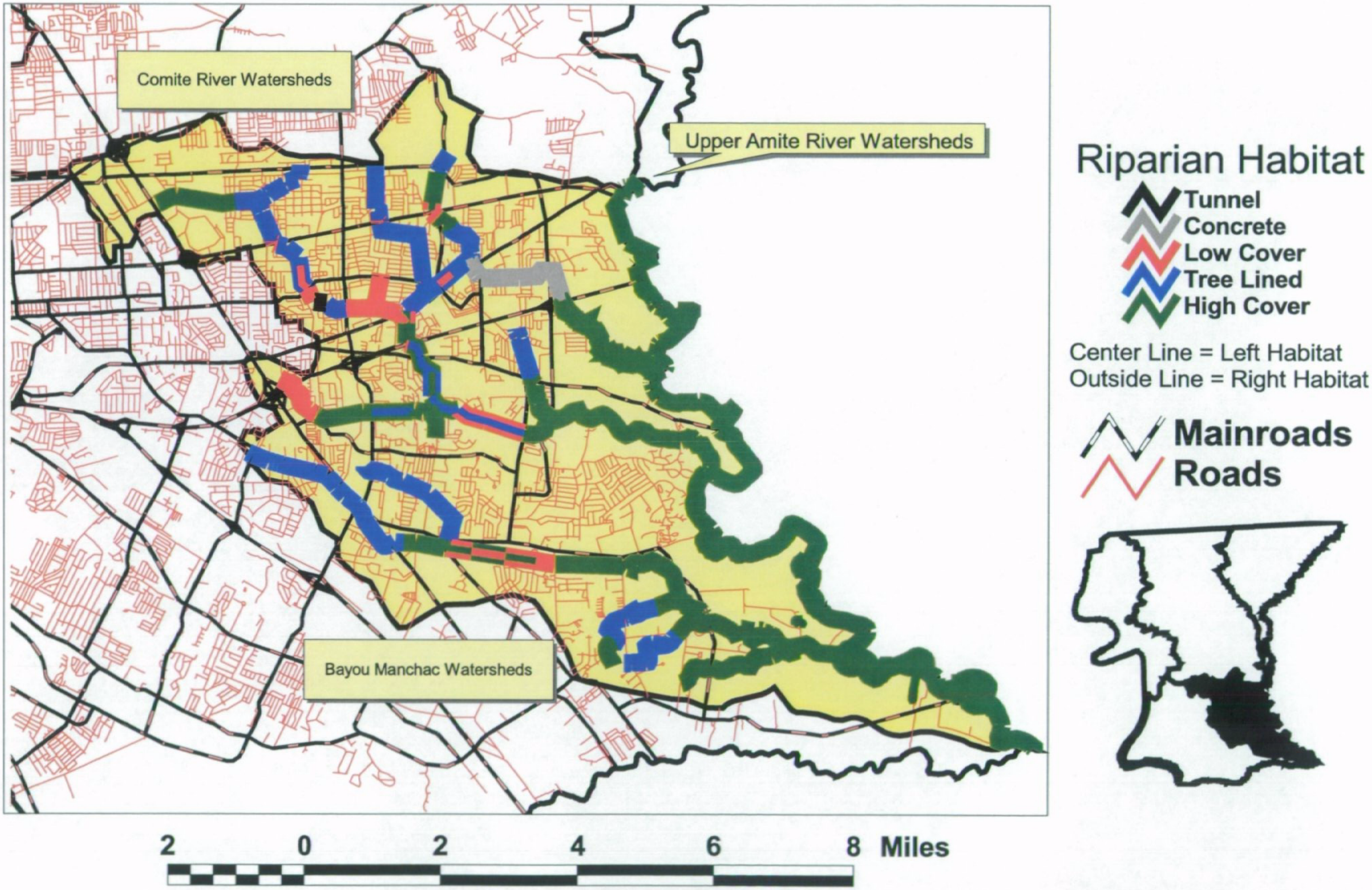

Figure C-8 Riparian habitat in the Lower Amite River Basin

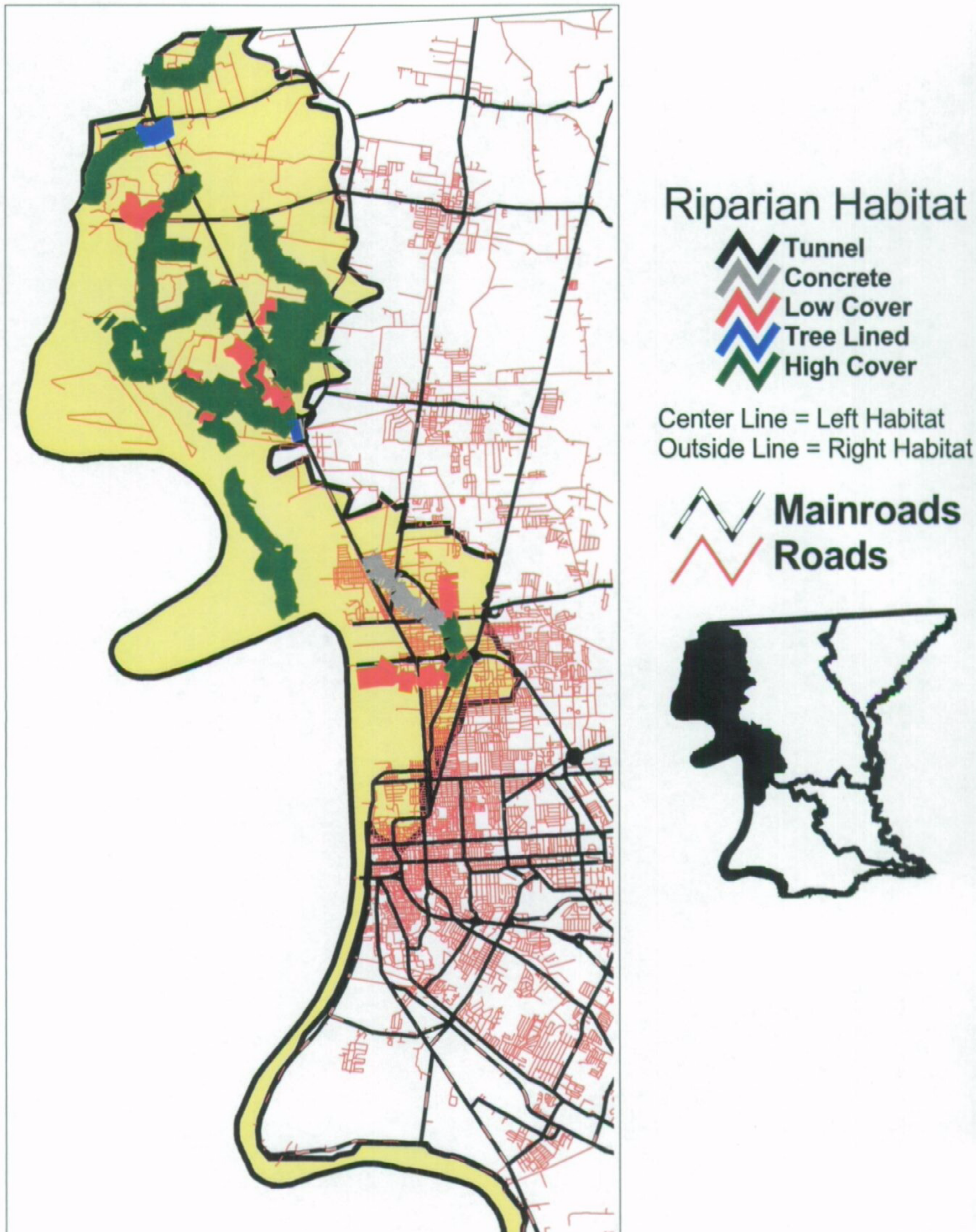

Figure C-9 Riparian habitat in the Mississippi River Basin

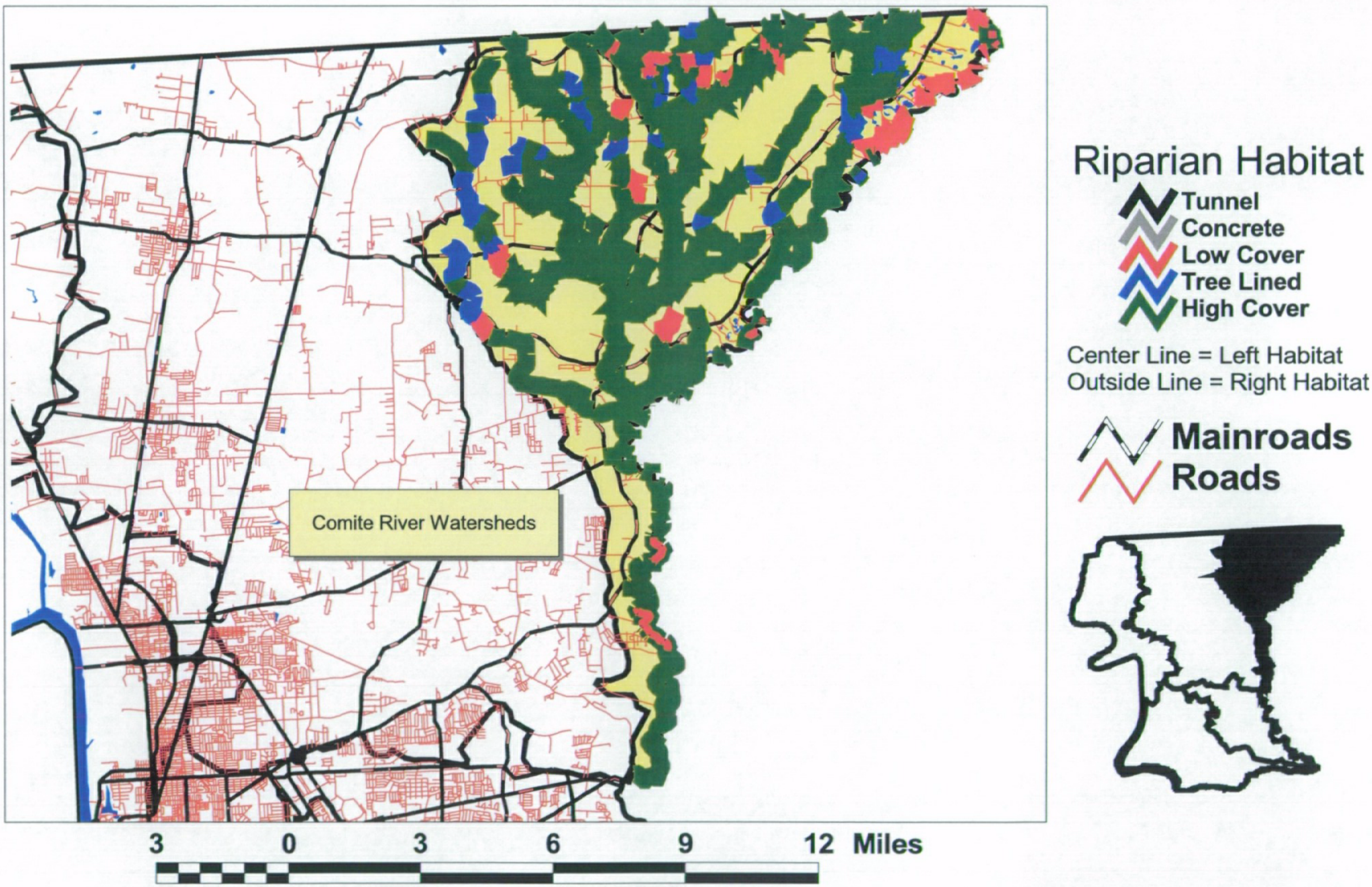

Figure C-10 Riparian habitat in the Upper Amite River Basin

Appendix D – Macroinvertebrate Diversity Survey

Table D-1.
Summary of Macroinvertebrate Sample Site Descriptions

Sample Site	Substrate	Stream Depth (ft.)	Water Appearance	Comments	Index Value	Water Quality
Clay Cut Road	Concrete	0.30	Clear	Cover of filamentous algae, mosquito fish present	4	Poor
South Ridge Drive	Silt Cobble Organic matter	2.00	Clear	Lots of litter, White heron feeding	11	Fair
Corporate Blvd. (Upstream)	Silt Cobble Organic matter	1.50	Clear		9	Poor
Corporate Blvd. (Downstream)	Silt Cobble Organic matter	1.50	Clear		7	Poor
Bluebonnet Blvd.	Silt Organic matter	2.00	Turbid	exhibited diversity, higher turbidity	9	Poor
Highland Road	Silt Organic matter	3.00	Turbid	Many large fish seen moving, wildlife tracks on banks	N/A	N/A